ONTARIO
INDUSTRIAL WASTE MANAGEMENT
COMMUNITY SEMINARS

June-July, 1983.

INTRODUCTION

The following material has been assembled to provide you with a perspective on waste management systems now operating in Europe and the United States, to review the reasons why such a facility is needed in Ontario and to examine the alternatives.

We suggest that you examine the technical material on waste reduction, waste recovery and waste disposal with care, since the three articles, taken directly from "Profits From Pollution Prevention", published by Pollution Probe, provide a wealth of detail about the means by which industrial wastes can be reduced, recycled, neutralized or destroyed.

The remaining material centres on the special waste situation in Ontario and the activities of OWMC, including the most recent summaries of progress and plans for the future.

This material is designed to supplement and complement the information which will be exchanged in small groups during the Conference. It has been taken directly from trustworthy source material drawn together during the past two years. We hope you find it helpful in preparing for the meeting.

Sincerely,
Rodger Schwass,
Conference Chairman

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D E N M A R K

Foreign Waste Dispcsal Sets a Pace for the U.S.

Chemcontrol A/S
Dagmarhus - DK-1553 Copenhagen V.
Denmark

EXTRACT FROM CHEMICAL WEEK MARCH 25, 1981

environment

Foreign waste disposal sets a pace for the U.S.

"It's all very modern. They use state-of-the-art technology, and their housekeeping is magnificent—they look like chemical plants, not dumps." Thus does John Lehman, director of the U. S. Environmental Protection Agency's Office of Solid Waste, wistfully describe the centralized chemical-waste systems he visited in Denmark and West Germany. So integrated are those collection and disposal operations that, in Lehman's opinion, they could well serve as models for the U.S. chemical industry and federal and state governments, all of which are wrestling with the implementation of the Resource Conservation and Recovery Act (RCRA).

The Danes, who started up their system—Kommunekemi—in 1975 (*CW, Apr. 30, 1975, p. 54*), are now marketing it through Chemcontrol, a sales organization composed of private engineering firms and government agencies. In December, Chemcontrol signed an agreement with Finland's Suomen Ongelmajate to plan a Kommunekemi-like facility that will be jointly owned by industry and the Finnish government.

Kommunekemi became a gleam in the eye in 1971, when the National Assn. of Danish Municipalities proposed the idea of a central collection and disposal system to the Danish Parliament. One year later, the proposal resulted in the Danish equivalent of this country's RCRA.

A Danish tanker collects chemical wastes.

There was relatively little opposition when Kommunekemi was put together in the early 1970s—only "a bit of local grumbling," says one source. The association of cities was able to raise funds for capital investments—the current total of $20 million will soon be increased by $10-12 million. The money was loaned interest free for five years.

At the center. The heartbeat of Denmark's waste-disposal system is the Kommunekemi waste-treatment and disposal facility in Nyborg, the country's geographic center. There, the only facility developed to serve an entire country handles 55,000-60,000 metric tons/year of waste. In the U.S., where several disposal sites have more than three times that capacity, that doesn't sound like much. But the Danish operation is fully integrated: It controls collection and transportation of wastes; and it provides incinerators, landfills, and chemical and physical treatment.

Kommunekemi earns an annual profit of about $1 million on revenues of about $5.5 million. Users are charged an average of $100/m.t. for disposal, which accounts for 95% of Kommunekemi's income. The remaining 5% is derived from the sale of steam, which is piped into the Nyborg district heating system.

CHEMCONTROL A/S

DAGMARHUS - DK-1553 COPENHAGEN V. - DENMARK - TELEPHONE 01-14 14 90 - TELEX 15508 KMPSX DK

Chemcontrol A/S is founded by Kommunekemi a/s, Kampsax International A/S and I. Krüger A/S, with the purpose of conducting consultant engineering services in the field of oil and chemical waste product disposal. The National Agency of Environmental Protection acts as consultant for the company.

A report from

CHEMECOLOGY

Published by the Chemical Manufacturers Association to promote a clean environment

June 1981

Denmark Controls Hazardous Waste With Central Disposal System

Industrialization came relatively late to Denmark, a small Scandinavian nation and a primarily agricultural one until the twentieth century. While its heavy manufacturing growth after World War II brought Denmark closer to economic self-sufficiency, it also brought problems of environmental pollution.

Waste is shipped from central collection stations to the Kommunekemi by rail.

This diagram explains how the Danish system works.

To meet Danish environmental protection needs, the Ministry of Environment was formed in 1971. Through the legislative authority of the ministry and its advisory National Agency of Environmental Protection, Denmark developed a centralized hazardous waste treatment system.

The Danish system uses a central treatment plant, called the Kommunekemi, that is fed by a waste collection and transportation net covering the country. A single corporation, Chemcontrol, coordinates the system.

Chemcontrol was founded by the National Agency of Environmental Protection acting in conjunction with Danish civil engineering firms.

Regulations governing disposal of waste oil and chemical wastes require industry to notify municipal councils if they generate more than 150 liters per year. The wastes must be delivered to a location selected by the local council, unless the industry demonstrates that it can safely treat and dispose its own waste.

Generally, 39 types of chemical wastes are covered by the notification requirement. Special waste cards for each of the categories have been prepared, and must accompany the waste during shipment. The cards give chemical data plus guidelines for safe handling, packaging and transportation of the waste.

Private citizens are not covered by the notification requirements, but are responsible for making sure their wastes are properly disposed.

To make waste collection possible, municipal councils throughout the country established local networks. They include a central collection station collecting waste oil and chemical waste for several municipalities, as well as smaller single municipality collection stations for household waste oil and chemicals.

Waste materials usually travel by road from collection stations or industries to the central stations. Then, they're shipped by rail to the Kommunekemi.

A declaration describing the waste and its characteristics is completed by the waste supplier and travels with the waste to the treatment facility in Nyborg, near the center of Denmark. The declaration is similar to the manifest required by the U.S. Resource Conservation and Recovery Act.

At the Kommunekemi, declarations are processed. Then, the wastes are released for appropriate treatment.

The Kommunekemi has a waste oil plant that can cleanse up to 15,000 tons per year. It has an inorganic chemical waste plant and two incineration facilities. One incinerator plant destroys liquid and solid wastes with low sulfur and halogen content. The second incinerates pumpable halogen wastes. A solvent plant is planned for the future.

Waste producers pay for the treatment. The costs depend on the type of waste.

FACTS ABOUT CHEMCONTROL

Chemcontrol A/S was founded by an initiative taken by Miljøstyrelsen, (the Danish National Agency of Environmental Protection), Kommunekemi a/s, Kampsax International A/S, and I. Krüger A/S, all of whom are represented on Chemcontrol's Board of Directors and where the last 3 companies mentioned are also stockholders in the corporation. The parent companies with their additional know-how and specialization stand behind Chemcontrol which is further supported, for that matter, by consultancy agreements guaranteeing that the problems of clients will be conscientiously solved using the most advanced technology and latest findings.

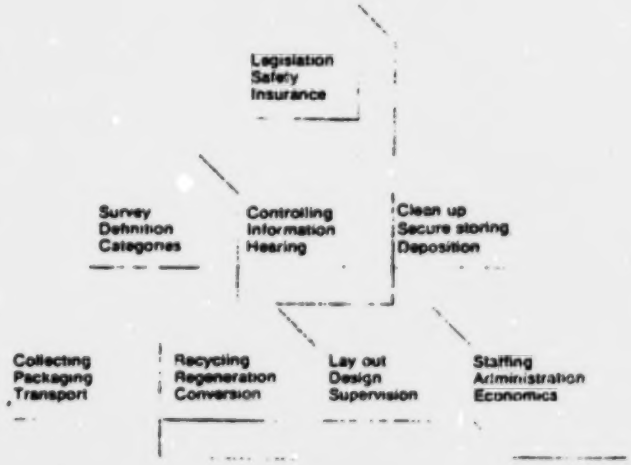
The project team will be selected from the Chemcontrol Group according to the scope of the work programs:

- Chemcontrol A/S (CC)
- The Danish National Agency of Environmental Protection (NAEP)
- Kommunekemi a/s (KK)
- Kampsax International A/S (Kx)
- I. Kruger A/S (IK)
- A/S Niro Atomizer (NA)

This is how Chemcontrol operates...

The consulting service offered by Chemcontrol includes all phases for the setting up of a disposal system for waste oil and chemical wastes.

We offer assistance in the planning and establishing of a whole system, or, according to the clients individual needs, of adapting certain elements of the »package«.



The project includes all phases connected with the planning and establishment of the system. The planning includes a whole range of activities connected with the technical, managerial, and economical aspects of the project from the formulation of the problem to the start up of systems and training of staff.

Working abroad Chemcontrol offers direct consultant assistance to a client, or if it is found appropriate the company works on at joint venture basis or as subconsultant to a local partner.

Formulation of the problem

Collection of existing data

Preliminary study

Supplementary investigations

Alternative plans for evaluation

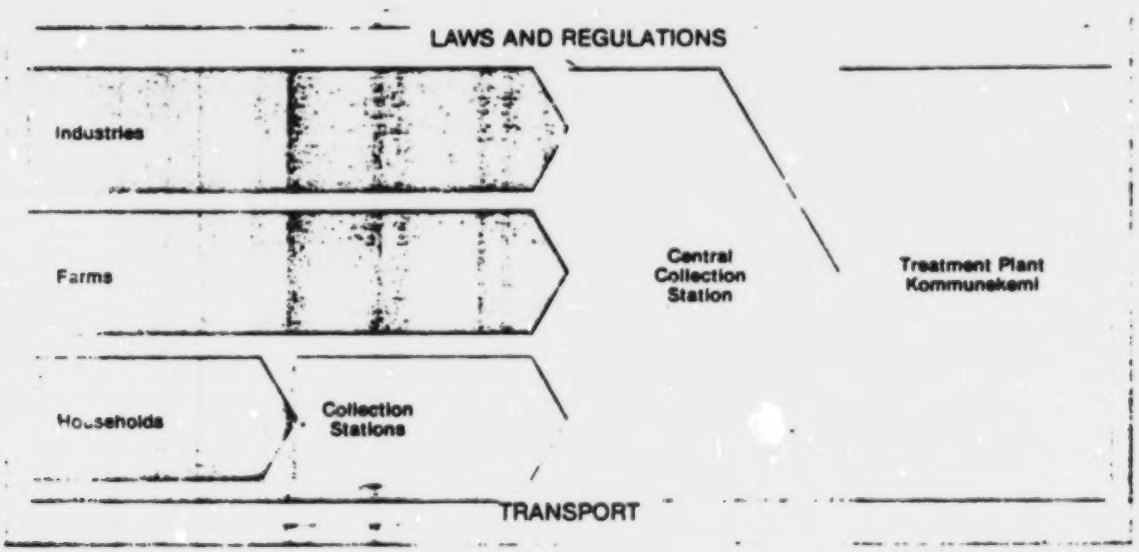
Design

Detailed design

Supervision

Start up and training

THE DANISH SYSTEM



G E R M A N Y

Disposal and Recovery of Special Wastes in Bavaria

By: Franz Defregger
Bavarian State Ministry for Development and Environmental Questions, Munich, Federal Republic of Germany

DISPOSAL AND RECOVERY OF SPECIAL WASTES IN BAVARIA (ABSTRACT)

1. Introduction

Bavaria is the largest Federal State in the Federal Republic of Germany with an area of 70,500 sq. kms. and nearly 11 million inhabitants.

With the increase of industrialization in Bavaria, the problems connected with the removal and disposal of special waste were recognized at an early stage.

'Special Waste' - this is waste and residues from industrial plants which, due to their composition, cannot be disposed of together with domestic refuse. As compared to the quantity of domestic refuse in Bavaria (nearly 3.4 million tons per year), special wastes are of a relatively small quantity (nearly 350,000 tons per year), however, special equipment and the application of special methods are needed to enable such wastes to be disposed of properly.

2. Institutions of Disposal of Special Wastes

There are two organizations in Bavaria:

- 1968, for the industrial area Nürnberg-Fürth-Erlangen (1.5 million inhabitants), the disposal of special waste was organized by a municipal co-operative called "Zweckverband Sondermüllplätze Mittelfranken", with its disposal facility at Schwabach (incineration, chemical treatment, qualified depository for 0.5 million m^3 volume).
- The company for Disposal of Special-Waste in Bavaria (Gesellschaft zur Beseitigung von Sondermull in Bayern mbH), GSB for short, was established in 1970. Its stock fund amounts to DM 15 million.

  Partners in the company are:
  - the Bavarian State (80%)
  - the municipal co-operatives (10%)
  - 50 industrial corporations (10%) (as of May 25, 1983)

The task of GSB is to provide and operate facilities necessary for the disposal and recovery of special waste in the whole of Bavaria. The activity of the company is conducted on a public welfare, non-profit basis and is principally limited to the territory of Bavaria, though wastes from outside of this state can be accepted.

3. Collecting Points and Disposal Facilities

The GSB operates a network of regional collecting points and several central disposal facilities. At present in Bavaria

- 10 regional collecting points and
- 3 central special-waste disposal facilities

are in operation, while the Special-Waste Disposal-Plan of the state provides for a total of about 20 regional collecting points (see Fig. 1).

The special waste is temporarily deposited at the collecting points, where it is classified for bulk transport to the disposal plants.

In addition, the collecting points are responsible for pre-treating waste like

- neutralization
- de-watering
- emulsion separation
- sludge thickening.

The central disposal facilities are plants for decontamination, water purification and incineration as well as qualified depositories. The central plant "Ebenhausen/Gallenbach" (near Munich) is the most modern of its kind in the Federal Republic of Germany and consists of:

- facilities for analyzing refuse (central laboratory)
- chemo-physical treatment plants (capacity 32,000 tons per year)

- incineration plants (2 rotary kilns, capacity 25 Gcal/h that means 40,000 tons per year.)
- qualified depository for 1.5 million m^3 gross storage volume near Gallenbach (capacity for nearly 20 years).

4. Recovery Facilities

As a consequence of the growing shortage of raw materials, the emphasis of waste disposal is increasingly shifting towards the reclamation and recycling material. Since 1974, the GSB has been operating a plant in Geretsried near Munich for distilling used solvents, varnish thinners, degreasing agents and the like. Nearly 2,000 tons of waste per year are recycled.

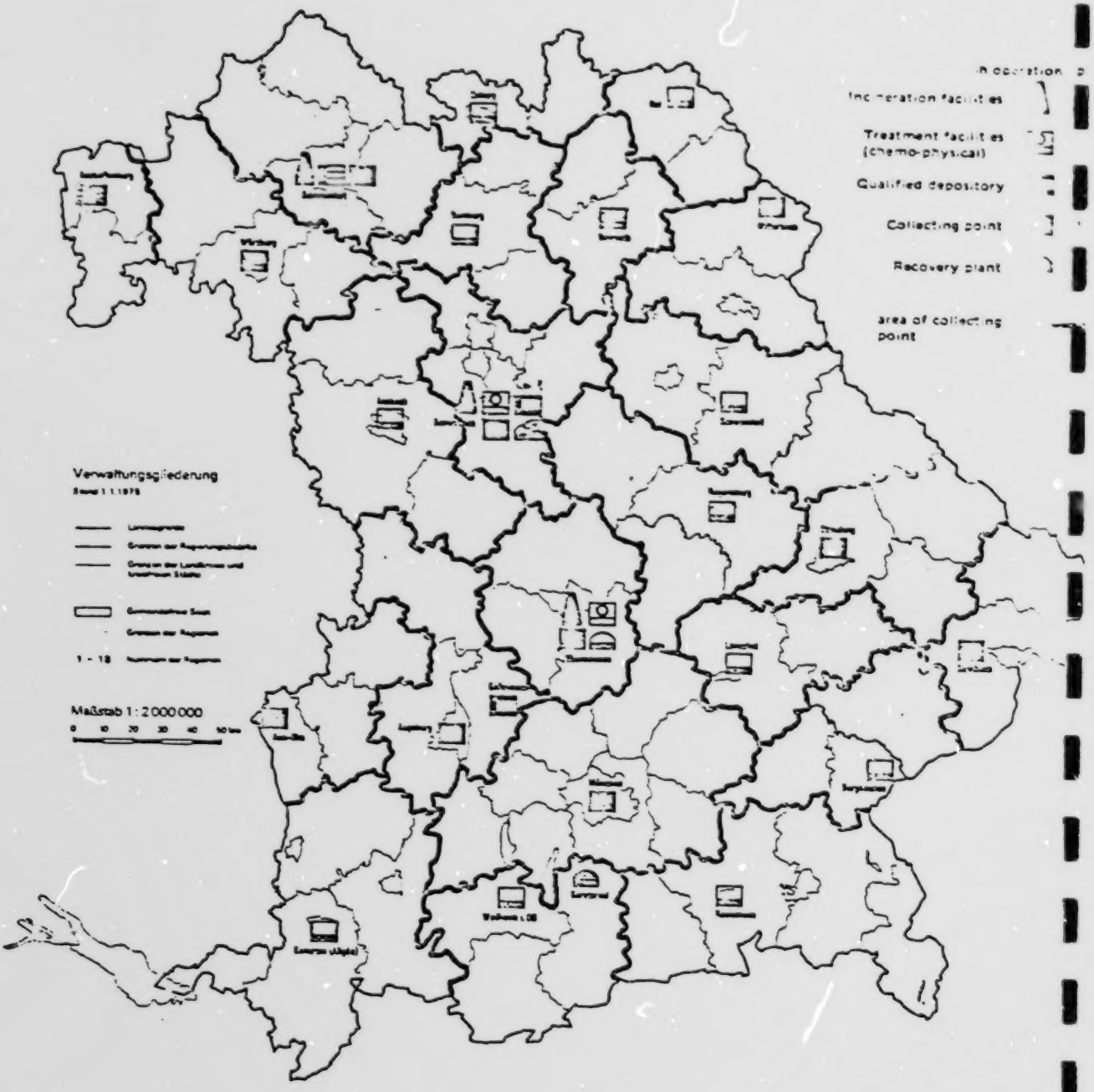
5. Investments and Financing

The working disposal facilities in Bavaria have required an investment of DM 80 million in the last ten years. Financing is handled through subsidies, government loans and favourable interest terms (DM 50 million) and the company's own resources obtained by economic activity.

Figure 1

Disposal of special waste in Bav

Situation 1979 and Plan



Published 1979 by Bavarian State Ministry for Development and Environmental Questions

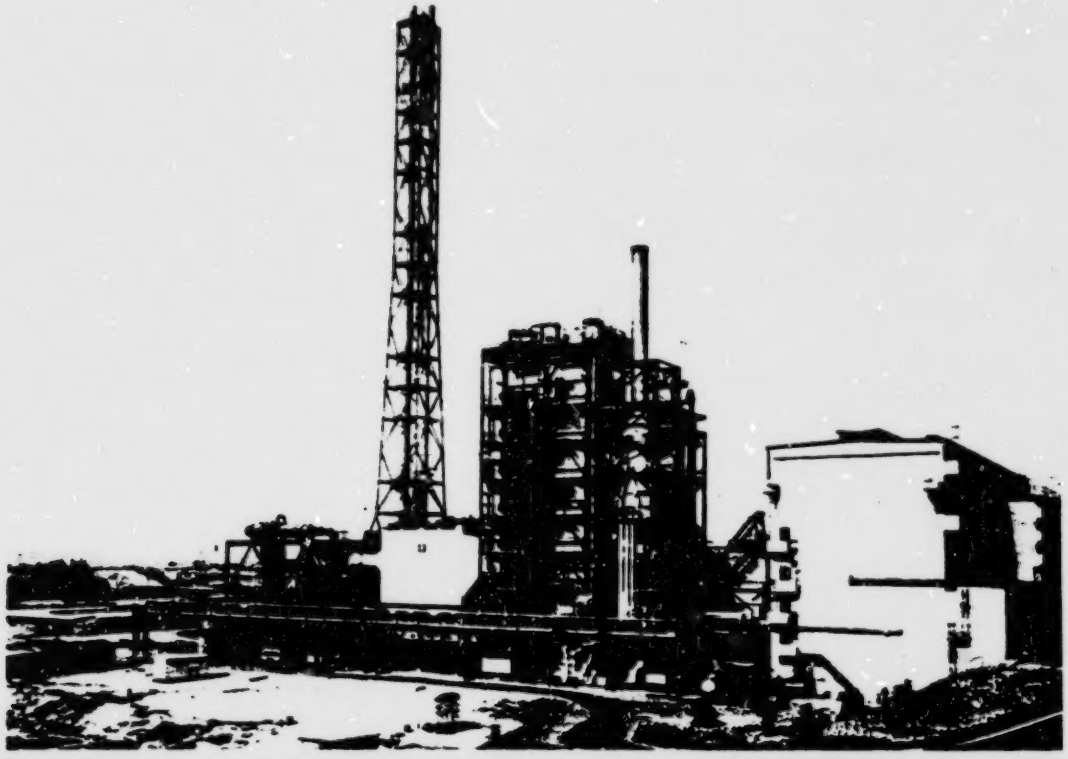


Fig. 1—Over-all view of the No. II incinerator system with flue-gas scrubber, seen from the west.

How Bayer incinerates wastes

This large chemical waste disposal system handles 25,000 tons per year of special wastes and produces 140,000 tons of steam while meeting current environmental rules

H. W. Fabian, P. Reher and **M. Schoen,** Bayer AG. Leverkusen, Germany

AFTER APPROXIMATELY one year of trials the No. II incinerator system at Bayer's Leverkusen plant was commissioned for regular service in November 1977. The construction of this system with downstream flue-gas scrubber had become necessary as a result of the increasing volume of waste and the additional requirements imposed for the disposal of "special waste."

The system's capacity allows the incineration of approximately 25,000 metric tons of special wastes per annum and produces approximately 140,000 tons of steam. It consists primarily of the waste bunker building, the rotary kiln with secondary combustion chamber including all feed devices for solid, paste and liquid waste, the heat recovery boiler, the electrostatic filter and the flue-gas scrubber which in turn consists of the injection cooler, two rotary scrubbers and one jet scrubber.

The purified flue-gas is heated in two heat exchangers and discharged by a suction blower via a stack of 100 m heighth. The stack is fitted with sensors and apparatus for the continuous measurement and recording of the type and quantity of the emissions. The scrubbing water is transferred to the company's own waste water treatment plant. Solid ash and dust are deposited in licensed disposal sites.

The system requires an operator staff of 35 persons including the instrumentation and maintenance personnel. The acquisition cost was DM 27 million. The system concept was developed in collaboration with L.&C. Steinmueller, D-5270 Gummersbach. Steinmueller was also the design and construction contractor. The operating cost is DM 10 million per annum. The average incineration cost is DM 400 per ton of waste.

Background. In 1973 the construction of a second incineration system with downstream flue-gas scrubber was decided as a result of the increasing volume of "special waste" generated by the plants of Bayer AG.

It was planned to use this system for the disposal of all "special waste" as defined in § 2.2 of the Waste Disposal Act (Abfallbeseitigungsgesetz) dated June 7, 1972, and in accordance with the Federal Anti-Pollution Act (Bundesimmissionsschutzgesetz—BImSchG) dated March 15, 1974, and the Technical Directive on the Prevention of

HOW BAYER INCINERATES WASTES

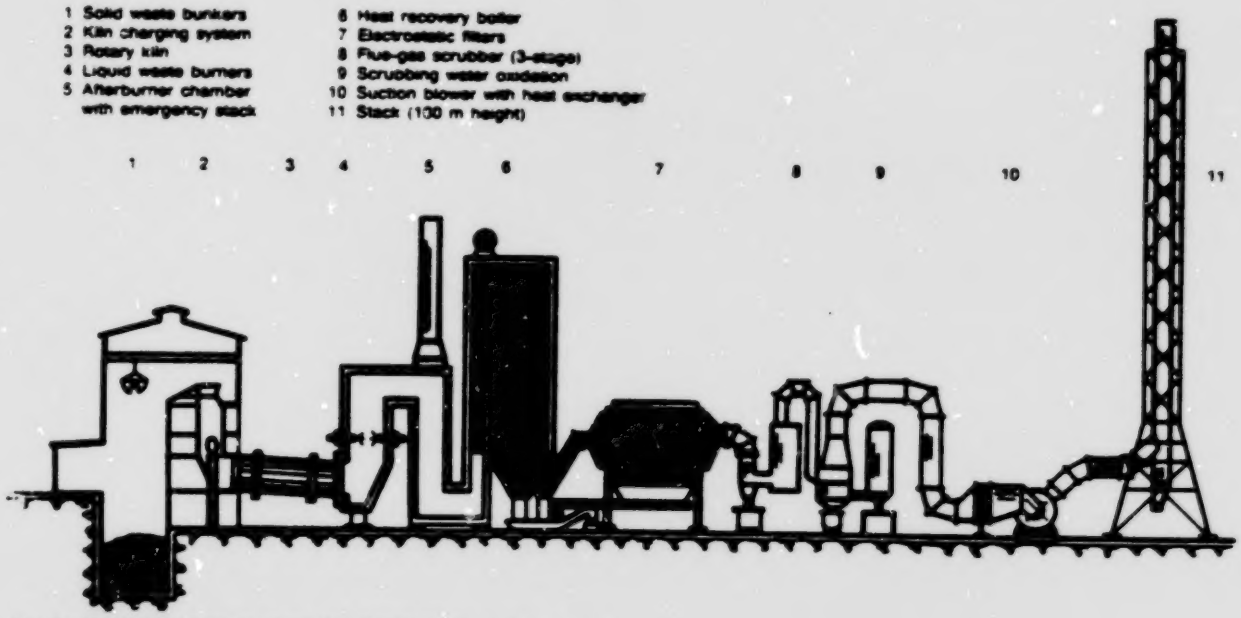

1 Solid waste bunkers
2 Kiln charging system
3 Rotary kiln
4 Liquid waste burners
5 Afterburner chamber with emergency stack
6 Heat recovery boiler
7 Electrostatic filters
8 Flue-gas scrubber (3-stage)
9 Scrubbing water oxidation
10 Suction blower with heat exchanger
11 Stack (100 m height)
1 2 3 4 5 6 7 8 9 10 11

Fig. 2—Process schematic of the No. II incinerator system.

Air Pollution (Technische Anleitung zur Reinhaltung der Luft—TA—Luft) dated Aug. 28, 1974.

The following requirements were imposed on the design and operation of this system and the clean incineration of the "special waste" involved in accordance with the statutes:

1. Incineration must always be preceded by careful analysis and classification of the waste in order to determine the best suited treatment method.
2. The design, process technology and mode of operation of the incinerator system must be suitable for adaptation to the specific waste problems encountered, i.e., the system must be designed so that any change in the quantity and composition of the waste will not cause any malfunction in the process.
3. The design of the combustion spaces and heat recovery systems as well as the materials used for them must minimize the flue gas damage.
4. Finally, the flue-gas scrubbers must be designed so that removal of the pollutants from the flue gas is ensured regardless of quantity and ratio between the individual flue gas components.

SPECIAL WASTE

In order to facilitate special waste handling and to allow a certain classification which is also required for intermediate storage, this waste type was roughly classified into four categories on the basis of the chemical properties:

1. Halogen, nitrogen, sulfur, phosphorous and silicon-containing production waste,
2. Toxic, spontaneously igniting, spontaneously decomposing and spontaneously polymerizing waste as well as waste generating strong odors,
3. Waste of high reactivity which may react spontaneously with other waste or have a strong corrosive effect, and
4. Miscellaneous waste consisting of minor quantities of highly different waste whose composition is mostly unknown.

Classification under physical aspects would have been possible on the basis of the state of aggregation (solid, liquid) or on the basis of their calorific value which varies from 0 to 40,000 kJ/kg. However, in practical operations such a classification would not have been feasible since the chemical properties dominate.

INCINERATION PROBLEMS

In addition, the concept for the No. II incinerator system had been influenced by some basic considerations arising from the specific incineration problems of some waste types. As an example for these problems, the disposal of chlorine-, phosphorous- and silicon-containing waste and the heavy-metal-containing ash generated upon incineration shall be explained in more detail.[1]

Incineration of chlorine-containing waste. In addition to CO_2 and H_2O the incineration of chlorine-containing waste primarily produces HCl. The concentration of the generated HCl can be estimated fairly rapidly if the chlorine content of the waste and the excess air number are known. Thus it can be shown that the limit of 100 mg/nm³ HCl in the exhaust air, which the German air pollution directive requires, will be reached and exceeded even when the waste has a very low chlorine content. For instance, the flue gases of waste containing

0.2% by weight chlorine, incinerated with 50% excess air, i.e., at $\lambda = 1.5$, already contains 160 mg HCl/nm³. For waste whose chlorine content may be 60% by weight and more, the HCl content in the flue gas will be in the order of several grammes HCl/nm³. The possibility that major quantities of HCl may be generated requires very careful selection of materials and imposes maximum requirements on the efficiency of the flue-gas scrubbers.

Apparently caused by HCl and supported by other aggressive volatile flue-gas components, corrosion damage was also temporarily encountered on system components which, due to their composition of materials, should have resisted this corrosive attack. Some parts made of Hastelloy C in the injection cooler, in the rotary scrubbers and in the droplet traps were completely destroyed after only a few thousand operating hours. Similar damage was also encountered in the heat exchanger and in the suction blower. These damage and malfunction problems have now been corrected through design changes and through the use of improved materials.

In the combustion of chlorinated hydrocarbons the formation of elementary chlorine through oxidation of HCl cannot be theoretically excluded. Chlorine represents a certain danger to metallic system components. The thermodynamic data of this oxidation process, which is referred to as the Deacon reaction, show that chlorine formation is strongly reduced with increasing temperature and increasing water content, but is facilitated with decreasing temperature and increasing HCl and oxygen concentration. At the usual combustion temperatures between 1,200 and 1,300°C, however, the theoretically possible chlorine quantity is only 10 mg Cl_2/nm³ which is negligible.

Considerably more significant, however, is the question as to the change of equilibrium taking place as the flue gases pass through the ducts of the heat recovery boiler until they have cooled to approx. 300°C. In this temperature range the equilibrium concentration of chlorine is so high that the corrosion of the boiler and system components must be feared. It is a known fact that carbon as well as iron and copper oxides have a catalytic effect and accelerate the equilibrium. In fact, a concentration of 200 mg Cl_2/nm³ has been measured in the flue gas during the incineration of copper-containing chlorinated hydrocarbons. The combustion space temperature was 1,100°C, and the flue gases passed the temperature drop from 1,100°C to 600°C in approximately 2 seconds. In addition, the catalytic effect of dust from the electrostatic filter on chlorine formation was studied under laboratory conditions. For these studies a mixture of 90% by volume of air, 9% by volume of water vapor and 1% by volume of HCl was passed through a reaction tube at 500°C filled with glass wool and dust from the electrostatic filter, and the chlorine content determined at the outlet. After a residence period of 15 seconds, chlorine contents up to 800 mg Cl_2/nm³ were determined.

Similar reactions take place in the incineration of bromine and iodine-containing waste. As a result of the lower electron negativities of bromine and iodine, the unfavorable effect arises that the formation of the corresponding halogenated hydrocarbons will shift in favor of free halogens so that increasing quantities of free bromine and iodine are produced.

In order to avoid the problems in systems technology and apparatus involved in the possible occurrence of free halogens in the flue gas, it has been found advantageous to incinerate halogen-containing waste together with sulfur-containing waste. Apparently the SO_2 produced during this process will reduce the halogens present to the corresponding halogenides to a degree where not even traces of halogen can be identified by analysis. Therefore, the prerequisite for stopping the halogens in the flue-gas flow is to maintain a constant waste mix and an adequately great SO_2 concentration. As a result of this mode of operation it has been possible so far to avoid any corrosion damage by halogens.

Fig. 3—Bunker building for solid waste; delivery in tipping truck.

Incineration of polychlorinated compounds. Certain polychlorinated compounds may appear problematic from the point of view of incineration in that they are characterized by their increased thermal stability. Consequently, their complete incineration may require higher temperatures and longer residence times in the combustion zone. Our own studies in this field have shown that, at temperatures above 1200°C and minimum residence times of 1 second, it was impossible to identify any chlorinated compounds in the flue gas, the lower identification limit of the analysis being approximately 0.003 μg/nm³.

Incineration of organic phosphorous compounds. The primary combustion product of organic phosphorous compounds is gaseous phosphorous pentoxide. This compound has extremely unfavorable chemical and physical properties for the process of an incinerator system. Phosphorous pentoxide is fairly volatile, its vapor pressure being 10^{-2} Torr at 300°C which is equivalent to 170 mg P_4O_{10} per nm³, its melting point is 569° C and its boiling point 591°C. Being the anhydride of a strong tribasic acid, phosphorous pentoxide violently reacts with water even at elevated temperatures, forming metaphosphoric acid. Phosphates of varied basicity are formed in the presence of basic oxides or salts. At temperatures above 600°C reactions with airborne dust deposited on heat exchanger surfaces and on the internals of the electrostatic filters take place with the result that these loose deposits turn into sticky, firmly adhering and difficult to remove incrustations. This will result in increased pressure drop and reduced efficiency of the heat recovery boiler

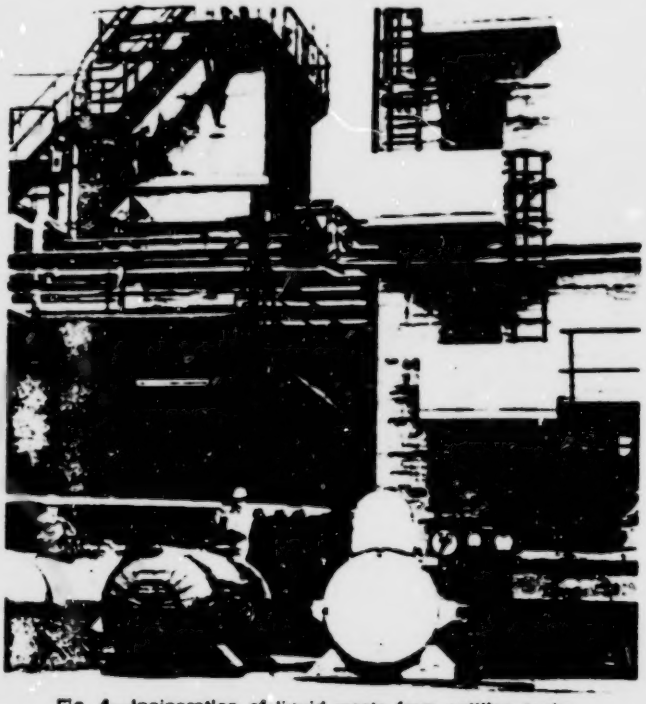


Fig. 4—Incineration of liquid waste from settling tanks.

and electrostatic air filters. In addition, reactions with the boiler walls cannot be excluded. The gaseous P_4O_{10} penetrates the dust deposits and reacts with the protective iron oxide layers on the boiler wall, forming iron phosphates. In addition, it has been observed that, due to the very small temperature interval between condensation point and melting point ($\Delta T = 22°$ C), when the phosphorous oxide-containing flue gases cool, it will easily happen that very fine aerosols are produced which are only highly inadequately separated by conventional dust traps. Many experiments and design modifications were necessary in order to find a solution for these problems. In the meantime the process technology and the plant design have been adapted to the point where no emissions are observed even under surging P_4O_{10} loads.

Incineration of organic silicon compounds. Extremely fine silicon dioxide particles are produced during the incineration of organic silicon compounds. SiO_2 has a very high melting point (1713° C) and high electrical resistance (10^{12}-10^{13} Ω/cm). Both are adverse properties from the point of view of optimum electrostatic dust separation. As a result of the very high melting point the SiO_2 aerosols from the primary process will not agglomerate into larger particles, and the separation efficiency of the electrostatic filter is correspondingly poor. Due to the high electrical resistance, the electrical charge is transferred very slowly from the deposits to the separation electrodes. The SiO_2 deposits have the effect of a dielectric, impeding the electron flux between spray discharge electrodes and separation electrodes which is necessary for dust separation.

It is found in day-to-day operations that during the incineration of silicon-containing compounds the separation efficiency will drop below 30 percent of the usual value in spite of increased field strength. In these cases the perforated plates, the spray discharge wires and the separation plates of the electric dust filters are subsequently covered with dust deposits up to 10 mm thickness. Normal vibrating devices are inadequate for the removal of this type of dust accumulation. Ninety-nine percent of this dust consists of SiO_2; its density has been determined at 0.05 g/cm³. Consequently, the incineration of organic silicon compounds usually requires extensive manual cleaning work in the electrostatic filter systems.

This is another case where the process was optimized through systematic experiments and some redesign to the degree where malfunctions of the type described above no longer occur.

Ash with heavy-metal content. One problem of special significance is the heavy-metal content of slag and ash. In addition to metal compounds which are insoluble in water, a great number of soluble metal compounds in the form of oxides, chlorides or sulfates are produced during the incineration of chemical waste. These compounds, contained in the slag and ash, are easily eluted when the slag or ash is flushed from the system, and thus may get into the waste water. The prevention of this contamination requires additional methods to reduce the heavy-metal content of scrubbing and slag water. One such method, for instance, is the precipitation of heavy-metal ions with milk of lime, forming hydroxides which are almost insoluble in water and can be filtered.

Another problem is the volatility of certain metal compounds. Some metal oxides and chlorides have such a high vapor pressure at temperatures from only 150 to 350°C that they will pass the electrostatic filters and, unless there is a flue-gas scrubber, would condense only after further cooling and discharge into the atmosphere. These include predominantly the oxides of arsenic, selenium and phosphorous as well as the chlorides of antimony, arsenic, iron, mercury, tin, cadmium, bismuth, zinc and tantalum. Since some of these compounds are highly toxic, the flue-gas scrubbers must be extremely efficient. For instance, a mercury content of only 0.1% by weight in waste would be sufficient to cause an emission of approximately 120 mg $HgCl_2$/nm³ in the exhaust gas. Or, during the incineration of waste containing 0.1% by weight of $CdCl_2$ and provided that all of the easily soluble cadmium chloride is dissolved in the slag water, the waste water, based on a realistic waste water ratio of 2 m³ per ton of waste incinerated, would contain approximately 500 mg $CdCl_2$/liter!

WASTE ACCEPTANCE

Waste generated in Bayer AG plants is first reported by the operating departments to the anti-pollution and waste disposal department, using an incineration permit accompanied by a 5 kg sample. This incineration permit includes data on the quantity, the precise designation and characteristic components of the waste to be incinerated. Other important information for waste disposal include the type of packaging and/or delivery to the plant, the date of delivery, the state of aggregation of the waste, its combustibility, the flash point, the ignition temperature,

the calorific data, its behavior upon heating, its boiling point, gas generation, reactivity with water, toxicity, any odors generated and the hazard class according to the Flammable Liquid Directive (VbF). Within the waste disposal department the waste acceptance and inspection laboratory group, on the basis of this information and if necessary its own laboratory studies, determines the technically and economically optimum waste disposal method (incineration with or without flue-gas scrubbing, incineration on the high seas, surface or underground disposal), completes the study by assigning an inspection number and communicates the result to the operating department concerned. If the waste disposal department proposes the disposal of waste by incineration, the waste will be delivered to the plant together with a waste way bill which lists predominantly the quantity, number and type of containers, the inspection number and the materials classification code. This materials classification code is important for computing the incineration cost. Practical experience has shown that a rough classification of combustible waste into eight materials classes is best. The incineration cost per materials class varies from DM 165/ton for liquid non-chlorinated waste to DM 885/ton for waste in small containers of highly variable content.

On the basis of the materials classification code the incoming waste is channelled to certain collection points by a control center. Solid halogen-, sulfur- and/or phosphorous-containing waste is collected in a bunker building. This bunker building includes four chambers having a capacity of 200 m³ each. On the basis of their basicity, neutral, basic or acid wastes are segregated and collected in a certain chamber each. The fourth chamber is available for special waste types. Liquid halogen-, sulfur- and/or phosphorous-containing waste is either incinerated directly from settling tanks (maximum capacity 10 m³) or collected in larger tanks (capacity approx. 400 m³) for intermediate storage. The method used is decided on the basis of the quantities generated and the chemical compatibility of the different waste types. Highly reactive, decomposing and/or generally difficult to handle waste is delivered in combustible plastic drums whenever possible (capacity 60 to 100 liters), handled via a separate drum elevator and dropped with drum into the rotary kiln for incineration.

NO. II INCINERATOR SYSTEM

The process concept for the No. II incinerator system was developed on the basis of the specific waste situation prevailing at Bayer's Leverkusen plant with due consideration to the theoretical studies above. The practical experience acquired in several years of operation on No. I incinerator system proved highly advantageous for the detailed planning effort.[2]

One new feature of this process is the multi-stage flue-gas scrubber system. Other design modifications included the configuration of the ash bunkers, the lay out and design of the afterburner chamber and the design of the heat recovery boiler.

The process schematic of No. II incinerator system is shown in Fig. 2. The functions of the individual system components are described below.

The most important technical specifications of this system have been compiled in the following table:

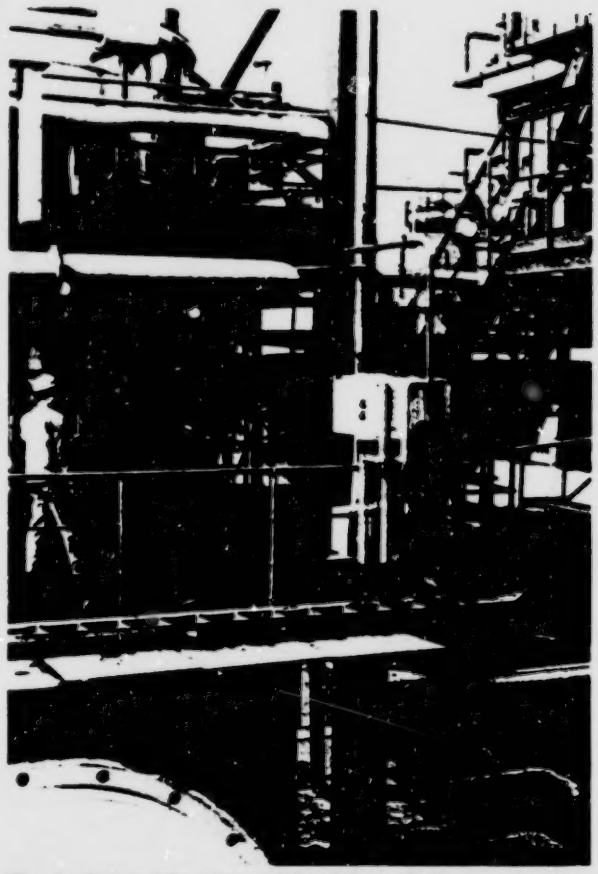


Fig. 5—Rotary kiln with upright, 2-duct afterburner chamber.

Bunker building		
Waste acceptance	4 chambers	200 m³ capacity per chamber
Waste charging system	1 grapple	0.8 m³ capacity
	1 plate conveyor	3-4 ton/hour
	2 slide gates	approx. 2-minute cycles
	1 charging ram	
	1 drum elevator	capacity 2-3 ton/hour
Rotary kiln		length 13.5 m diameter 3.5 m maximum thermal load 15 Gcal/hr (approx. 60 GJ/hr)
Solid waste incineration (see above)		
Liquid waste incineration	various settling tanks tank farm	capacity 3-5 m³ several tanks
	1 sustaining burner	capacity 300 kg/hr
Sludge incineration	1 injector	
Combustion air	1 blower	capacity 37,000 m³/hr
Cooling air	1 blower	capacity 5,400 m³/hr
Flue-gas outlet temperature		1,100 to 1,250° C
Afterburner chamber		
Secondary combustion	various settling tanks tank farm	capacity 1-5 m³ several tanks
	3 liquid burners	capacity 300 kg/hr per burner
	1 booster burner	capacity 50 kg/hr
Residence time		2-4 secs.
Flue-gas flow rate		40,000-50,000 nm³/hr, max. thermal load 20 Gcal/hr (approx. 80 GJ/hr)
Flue-gas outlet temperature		1,200-1,300° C
Heat recovery boiler		
Heat recovery	4 ducts	20 ton steam/hr, 38 bars, 350° C
Flue-gas outlet temperature		300° C
Electrostatic filters		
Dry dust removal		max. 20 kg dust/hr
Flue-gas scrubber		
Cooling and HCl separation	1 injection cooler	6-8 m³ water/hr
Residual dust separation	2 rotary scrubbers	5-25 m³ water/hr
Alkaline scrubber	1 jet scrubber	2-12 m³ water/hr
Sulfite oxidation	2 columns	
Exhaust air outlet temperature		60° C
Waste-air heating	2 heat exchangers	
Suction blower	1 ducted-impeller blower	capacity 60,000 m³/hr, drive rating 335 kW
Stack	insulated steel tube instrumentation and recording devices	height 100 m waste-air outlet velocity 12-15 m/sec.

HOW BAYER INCINERATES WASTES

CHARGING SYSTEMS

Solid waste charging. Solid waste is predominantly delivered in tipping lorries and collected in a sealed bunker building. Bulky materials are crushed in an impact mill. The charging hopper located above the rotary kiln inlet is charged by a grapple which is controlled from a fully air-conditioned operator cab which is sealed against the bunker space, using TV cameras and TV screens in a partially automatic, partially manual operation. The rotary kiln inlet is sealed against the bunker space by a lock fitted with two sliding gates. When the inclined sliding gate (in the drop chute of the rotary kiln inlet) is closed, a horizontal sliding gate located in the charging hopper will open.

A continuously operating plate conveyor belt located below moves the waste into the drop chute and deposits it on the inclined sliding gate. After a certain cycle time the horizontal sliding gate will open and the waste will drop down an inclined chute into the rotary kiln inlet. Any waste remaining on this inclined chute is pushed down by a ram.

Liquid waste charging. Liquid waste is delivered in sealed settling tanks having a capacity up to 10 m^3. Part of the liquid waste is incinerated directly from these settling tanks while another part is collected for intermediate storage in larger tanks (400 m^3 capacity) prior to incineration.

The transport of this liquid waste to the individual incineration points is accomplished via pumps or under nitrogen pressure (3 bars). Waste oil containing solids is first purified in a screening machine. The screen residue with a particle size of over 2 mm is moved by a compressed-air conveyor system (Gulliver gun) via a pipe line directly into the rotary kiln. Some of the waste delivered in settling tanks requires liquefaction through heating prior to combustion so that it can be pumped and atomized in the burners.

Steam outlets at up to 30 bars pressure are available for this purpose. After removal of the waste from the settling tanks through pressure, the tanks are de-pressurized via gas lines terminating in the afterburner chamber via intermediate safety devices. Waste liquids of low calorific value are atomized together with waste having high calorific value in multiple-fuel burners and incinerated. Atomization is accomplished either with steam or with compressed air.

These burners are located in the face side of the rotary kiln (1 burner) and in the wall of the afterburner chamber (3 burners, 1 booster burner). Burner monitoring is accomplished via a temperature sensor system. When the temperature drops below 1050°C a booster burner fired with natural gas is ignited, supporting the main burners. If the temperature continues to drop below 950°C, the fuel feed is interrupted by quick-action valves.

Charging of problematic waste in small containers. A separate system is available for charging the system with waste in small containers (cans, drums) which consist predominantly of an elevator, a roller conveyor, a lock with two sliding gates and a tilting table from which the small containers are dropped into the rotary kiln. This charging system is interlocked by the control system so that these small containers can be dropped into the rotary kiln only when the inclined sliding gate is closed. This insures that there will not be any interference between the drum charging system and the solid waste charging system.

Rotary kiln, afterburner chamber. The rotary kiln has a length of 13.5 m and an outer diameter of 3.50 m. The ceramic refractory liner has a thickness of 0.25 m. Consequently, its inner diameter is approximately 3 m. The rotary kiln is inclined 3 percent toward the outlet end.

The average rotating speed is approximately 9 revolutions per hour. It is infinitely variable between 7 and 24 revolutions per hour. The residence period of the waste in the rotary kiln is approximately 1½ hour. The internal temperatures reach 1,200 to 1,300°C. The hottest zone is located in the 7 to 11 m range. This is the zone where the strongest corrosion and erosion attack takes place. It is attempted to keep this attack within justifiable limits through the selection of extremely high-quality refractory materials and the continuous presence of a protective slag layer. At the discharge from the rotary kiln the slag drops into a water-filled plate conveyor slag removal system. The slag is free of any pollutants and can be deposited at a disposal site without any danger. The combustion air at a rate of approx. 40,000 nm^3/h is aspired from the bunker building and injected into the rotary kiln inlet below the solid waste charging system. The gross thermal rating of this rotary kiln is approx. 60 GJ (15 Gcal).

A circular, 2-duct, upright afterburner chamber is placed immediately downstream of the rotary kiln. Its height is approx. 9 m and its inner diameter 4.10 m. Both ducts are provided with a liner of high-temperature ceramic refractories. At approximately half the height of the first duct three liquid burners with an average thruput of approximately 300 kg/h per burner are distributed over the circumference.

In continuous operation this arrangement will achieve intensive admixture of the flue gases, combustion temperatures up to a maximum of 1300°C and a residence period of 2 to 4 seconds. Secondary air nozzles are installed above these burners for safety reasons through which additional combustion air can be injected. The entire inner space of the rotary kiln can be inspected from a port located in the base of the first afterburner duct. This has special advantages for the continuous inspection of the rotary kiln refractory liner and the protective slag layer in the kiln.

The second duct serves as an abatement chamber, and its bottom end has an ash collection space. This space can be cleared at certain time intervals through a port of several square meters area which is closed by four bulkheads; a front end loader is used for ash removal. Continuously operating conveyor devices have not been found feasible at this point. The afterburner chamber is designed for an over-all thermal rating of 80 GJ (20 Gcal).

Heat recovery boiler. The flue gases departing from the afterburner chamber at approx. 1200°C are cooled to about 300°C in the heat recovery boiler, generating approx. 20 tons of steam per hour at 38 bars and 350°C. This heat recovery boiler is an upright 4-duct boiler type. The first two ducts are empty ducts with radiative heating

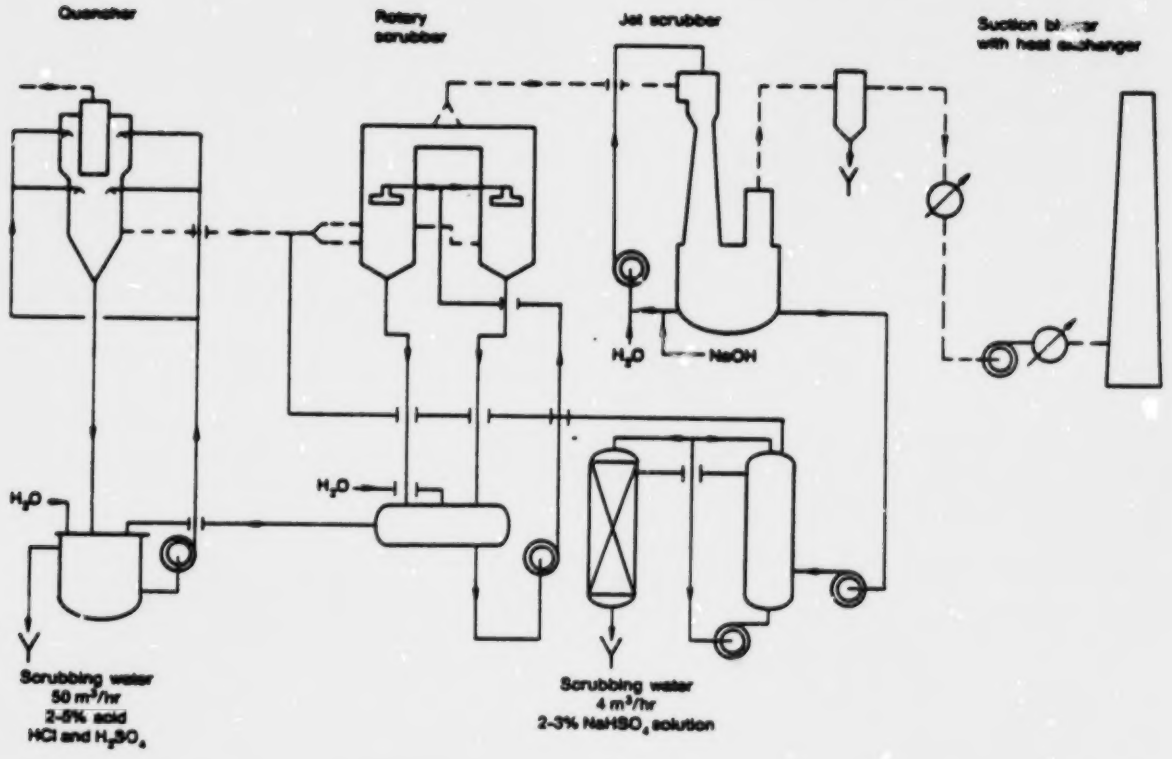


Fig. 8—Schematic of the flue-gas scrubber system.

surfaces. The last two ducts contain superheater, evaporator and economizer.

These boiler ducts have been made of finned tubing cooled by natural circulation. The contact heating surfaces have been welded from square tubing, forming smooth elements that are easy to clean with soot blowers, and connected to a forced circulation cooling system. The rotary kiln charging system and the heat exchangers used for heating the scrubbed flue gases are also installed in this cooling circuit.

Flue-gas scrubbers. In addition to CO_2 and H_2O the combustion of chemical waste produces predominantly SO_2, HCl, NO_x and dust as well as minor quantities of HF, SO_3 and P_4O_{10} whose quantities in the flue gas have been limited under the Anti Air Pollution Directive (TA-Luft) so that most of them must be scrubbed from the flue gas.

The concept definition for the flue-gas scrubbing system was based on the assumption that the flue gases will contain an average of 10 g HCl/nm³, 2.5 g SO_2/nm³ and 2 g dust/nm³, and that multiples of these concentrations may easily occur under peak loads. The quantities of HF, NO_x, SO_3 and P_4O_{10} were considered to be of minor significance.

The dry portion of the combination dry-wet flue-gas scrubbing system consists of the electrostatic filter and the 3-stage wet portion of the injection cooler (quench), the two rotary scrubbers in a parallel configuration and the jet scrubber.[3]

The majority of the dust is precipitated from the flue gases at approx. 300°C in the electrostatic filter. The filter efficiency is approx. 90-95%. The precipitated dust is removed by a scraping conveyor belt, collected in a covered tipping lorry and deposited at a solid-waste disposal site. This procedure has the advantage that any heavy metals contained in the dust and/or precipitated together with the dust cannot get into the subsequent wet scrubbing system where it would be dissolved in the form of chlorides or sulfates which could interfere with the biological treatment process of the liquid-waste treatment plant.

In the injection cooler the flue gases arriving from the electrostatic filter are cooled from 300°C to a level of 60-70°C and, at the same time, the majority of the HCl is separated. The cooling and scrubbing water required for this purpose is re-circulated. The evaporation losses are compensated by 6-8 m³/hr make-up water. The design of this section of the system and the materials used have been selected in accordance with the enormous thermal and corrosive loading of this section. The HCl concentration of the departing scrubbing water varies from 2-5 percent.

From the injection cooler the flue gas passes into two parallel rotary scrubbers. In these scrubbers the flue gases pass through a dense cloud of very fine water droplets generated by two rapidly rotating paddle-wheels.

These rotary scrubbers have three functions: (1) separation of any residual dust and extremely fine dust as well as volatile metal compounds; (2) separation of sulfuric acid aerosols which may be generated in considerable

HOW BAYER INCINERATES WASTES

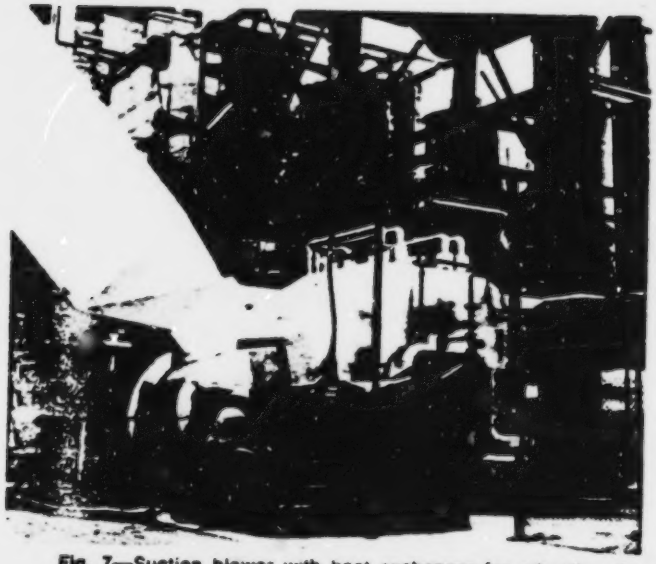


Fig. 7—Suction blower with heat exchanger for reheating the purified flue gases.

quantities in the injection cooler when the flue gases have certain compositions; (3) separation of the total dust if the electrostatic filter fails or if dust penetration occurs under excessive loads.

The scrubbing water is collected in a manifold and pumped out from this point. 2-5 m^3/hr fresh water is fed into this manifold in order to prevent any sludge accumulation. The overflow is passed to the collection point for transport to the liquid-waste treatment plant. Compared to other comparable scrubbers this rotary scrubber has the advantage of being insensitive to gas flow rate fluctuations, ensuring a high solids concentration (up to 200 g/liter) and having a lesser pressure drop (approx. 50 mm WC).

The latter effect was decisive for the decision in favor of this scrubber type. It meant that a flue-gas suction blower of lower pressure (400 mm WC), slower speed and lesser noise pollution could be installed.

Downstream of the rotary scrubbers the jet scrubber, using a weakly alkaline medium, is the third scrubbing stage. In this scrubber especially the SO_2 in addition to residual HCl, chlorine and NO_x are removed. In principle this scrubber is an over-dimensioned water jet pump. The scrubbing water is injected in the direction of the gas flow at a pressure of 3-6 bars. The downward velocity of the scrubbing water is 25-35 m/sec, that of the flue gas 10-20 m/sec.

As a result the scrubber automatically aspires the flue gas. The small pressure gain is adequate to overcome the internal drag. The scrubbing water is collected in a manifold and re-circulated. Scrubbing water losses are compensated by approx. 2 m^3 fresh make-up water per hour. The scrubbing water pH value is maintained constant at a certain adjustable value by means of a measuring and control device. The pH value of the scrubbing water is adjusted by adding sodium hydroxide solution.

The Na_2SO_3 and $NaHSO_3$ produced through reaction of SO_2 with sodium hydroxide in this jet scrubber must be oxidized into Na_2SO_4 prior to discharging the scrubbing water into the liquid-waste treatment facility. A specially developed 2-stage facility is used for this purpose where the oxidation is accomplished instantaneously at temperatures between 70 and 90°C. The discharged scrubbing water contains approx. 5% Na_2SO_4 and can be passed to the liquid-waste treatment plant together with the overflow from the injection cooler and the rotary scrubbers.

The entire wet section of the flue-gas scrubbing system is provided with an internal rubber liner for corrosion protection. Numerous instrumentation and control points monitor and control the scrubbing process. The cost of flue-gas scrubbing is approx. DM 100 per ton of waste incinerated.

Flue-gas drying and heating. In order to prevent condensation and corrosion in the stack and to ensure the rapid dispersion of the purified waste air in the atmosphere, two droplet traps and two heat exchangers (flue-gas heaters) have been installed between the jet scrubber and the stack. The first droplet trap is located immediately downstream of the jet scrubber and the second upstream of the first heat exchanger.

Waste-air heating is accomplished in two stages. The suction blower required to produce the necessary negative pressure in the different system components and to move the purified waste air into the atmosphere via an insulated stack of 100 m height is located between the two heat exchangers. The hot water required for the heat exchangers is obtained from the natural circulation of the heat recovery boiler.

This flue gas reheating process requires approx. 5 tons hot-water steam per hour, equivalent to 35,000 tons steam per annum at a cost of approx. DM 0.5 million for an average of 7,000 hours of operation per annum. If this reheating system were eliminated, the incineration cost could be reduced by 5-10%.

Efficiency. The energy efficiency of this system is computed as follows: under normal load approx. 1.8 tons of solid waste and 1.2 tons of liquid waste as well as approx. 0.6 tons of small-container waste are incinerated per hour. This waste has an over-all calorific value of approx. 83.7 GJ (20 Gcal). Out of this quantity, 41 GJ/hr (9.8 Gcal/hr), equivalent to 49%, is consumed for steam generation, and 9.2 GJ/hr (2.2 Gcal/hr), equivalent to 11%, is required for re-heating the purified waste gases. The remaining 40% includes 29.4% over-all heat losses (radiative losses on the rotary kiln, the afterburner chamber and the boiler, heat losses in the injection cooler and heat removal via the flue gases), and 10.6% for the operational uses of the plant.

ANTI-POLLUTION REQUIREMENTS

The license granted by the Düsseldorf Licensing Authority on Dec. 31, 1974, established the following maximum emission values for the No. II incinerator system:

SO_2	1,250 mg/nm^3 waste air
NO_x	1,000 " " "
HCl	100 " " "
HF	10 " " "
Dust	100 " " "
O_2	11% by volume

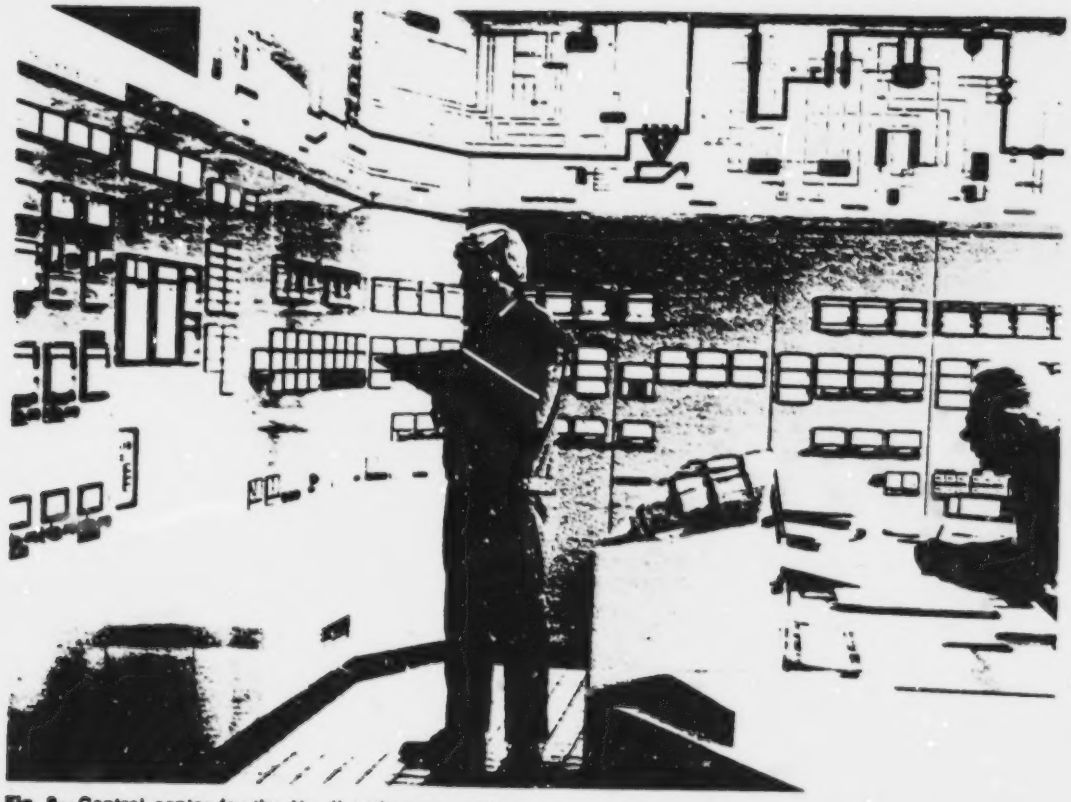


Fig. 8—Control center for the No. II incinerator system.

These components must be measured continuously for anti-pollution monitoring. For some components the monitoring is accomplished by means of continuously recording apparatus.

Systematic flue gas analysis under different loads and modes of operation was accomplished during the period from 6,000 to 8,000 hours of operation in order to study the efficiency of the flue-gas scrubbing system. The following results have been achieved:

Flue-gas component	Normal load (in mg/nm³)	Peak load (in mg/nm³)
SO_2	300	800
NO_x	400	up to 1000 and more
HCl	50	100
HF	3	5
Dust	20	100

On the whole the anti-pollution limits are maintained. They are occasionally exceeded with respect to NO_x. This has not been due to deficiencies in the apparatus or in the process, but to the fact that the physical and chemical properties of nitrogen oxides render any absorption very difficult. To this date no scrubbing process has been developed where separation efficiencies are achieved which are comparable to those achieved when scrubbing SO_2 and HCl.

In addition, the license requires all waste water and scrubbing water to be treated in a biological liquid-waste treatment plant.

Under normal operating conditions the afterburner chamber must be operated at a minimum temperature of 1000°C and a minimum residence period of 0.3 secs. The minimum temperature must be increased to 1200°C for the incineration of polychlorinated compounds.

The afterburner chamber temperature must be monitored by continuously recording apparatus. If the temperature drops below 1000°C, the charging system of the rotary kiln must be stopped.

ACQUISITION COST, PLANNING AND ERECTION TIME

The investment to acquire a capacity of 25,000 tons per annum of chemical waste amounted to DM 27 million. The system concept was developed jointly with L. & C. Steinmüller GmbH, D-5270 Gummersbach, who were also the designers and contractors for the construction of the facility. The planning period extended over two years. Erection required one year. During the three years of planning and construction this project secured approximately 100 jobs. The operating cost is DM 10 million per annum. Consequently, the average incineration cost is approx. DM 400 per ton of waste.

After trial operation of approx. 7,000 operating hours the No. II incinerator system of Bayer AG's Leverkusen plant was commissioned for regular service in November 1977. This system has passed the performance tests, achieving the specified operating parameters and has demonstrated its efficiency. It was presented to the public in a brief ceremony on Jan. 18, 1978.[4]

The trend of the waste situation during the next one or two decades can be estimated on the basis of two facts:

1. The Leverkusen plant has reached its maximum expansion level, and
2. Low-waste technologies are used with preference when new products are marketed.

The conclusion may be drawn that the amount of production waste of the type described in this article will

not increase significantly in the short run. Therefore, the construction of a third incinerator system is not contemplated.

POSTSCRIPT

One important item in the planning concept was the company requirement for a maximum of continuous mixing and transport of the different waste materials with respect to their calorific value and quantity in order to create uniform thermal conditions in the combustion spaces. In this respect a problem was created by the so-called small waste containers, cans or drums of 60 to 100-liter capacity and having a great variety of contents.

These small containers are filled with solid, paste and liquid production or laboratory waste in pure or mixed form whose calorific value fluctuates from 0 to 10,000 kcal/kg. The composition of these small container wastes may vary greatly. Often the contents are toxic, frequently they are not admixable, some of them will burn very slowly, but most of them spontaneously, and they sometimes react with great sensitivity to air and humidity.

The general practice of dropping the small containers into the rotary kiln without emptying them has process disadvantages. Occasionally there will be deflagrations with strong soot generation and excessive thermal and mechanical loading of the kiln refractories resulting from this practice.

In order to prevent these defects, paste and liquid small-container contents should be pressed into liquid nitrogen, granulated under nitrogen shielding, mixed and removed from the nitrogen bath into the rotary kiln by a conveyor system.[5]

This type of system would have been an elegant solution for all process problems arising in conjunction with these small-container wastes. Unfortunately, it would have caused some difficulties which were not accurately predictable and/or could not be exactly determined through preliminary studies:

1. The freezing characteristics of different organic wastes and waste mixtures vary greatly. One special disadvantage is that certain groups of materials will form continuous layers of incrustations floating on the nitrogen surface or adhering to the inner walls of the containers which do not settle on the bottom so that they cannot be removed and will gradually clog the system. Other groups of materials will freeze into minute crystals suspended in the liquid nitrogen bath, gradually enriching and forming a thick paste of crystals which finally agglomerates and blocks the conveyor system.

2. The small-container waste is mostly highly heterogeneous. Plastic film, plastic beakers, leather and rubber gauntlets as well as glass bottles are frequent accompanying products. Where these materials get into the liquid nitrogen bath, they will quickly clog the granulator and the transport screw. The necessary repairs are time-consuming and require many man-hours and, moreover, they are not entirely free of danger since reactive mixtures or explosive vapors/air mixtures can form during thawing, or toxic substances may be released.

Since these difficulties involved in retention of the concept could have been resolved only at additional enormous effort in terms of research and process development, if at all, it was attempted to optimize the combustion conditions through design modifications in the incinerator system itself and through process modifications so that even these problematic waste types could be properly disposed of without the disadvantages named above. These experiments which might be the subject of a later article have been successful every step of the way so that these problems may now be considered resolved.

This example was given to indicate that the apparently direct approach will not always yield the desired success. It may be possible that, in view of the increasing complexity of the problems, detours will become increasingly unavoidable which will be associated with high cost and will be very time consuming.

About the authors

HORST W. FABIAN *is department director responsible for waste disposal at the Leverkusen works of Bayer AG. Dr. Fabian obtained his technical degree from the Technical University in Hanover, Germany, and joined Salzdetfurth AG where he was head of the bromine plant and the laboratory before transfering to Chemische Dungerfabrik AG. He joined Bayer AG in 1965 working on the operation of incineration plants for chemical waste, sewage treatment plants and chemical process water waste treatment.*

PETER REHER *is group engineer responsible for the waste disposal and water pollution control plants at Leverkusen for Bayer AG. Dipl.-Ing. Reher studied process engineering at the Technical University in Aachen and first joined Uhde in Dortmund. He first joined Bayer AG in the planning and coordination of the construction of sulfuric acid plants and in their operation.*

M. SCHOEN *is head of Incinerator Plant II at Leverkusen for Bayer AG. Dr. Schoen studied chemistry at the Humbolt University and the Technical University of Berlin. He joined Bayer AG in the Enamel Department and became head of the laboratory for industrial scale manufacture of glass fiber products.*

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F R A N C E

Société d'Assainissement Rationnel
et de Pompage

By: J. B. Leroy

This is an operating facility in France which has to compete with other waste disposal options.

SARP - INDUSTRIES

1. Introduction

In addition to incineration and dumping, physical-chemical processes have their own specific place. Making use of techniques of the same family as those producing them in order to destroy certain refuse from the chemical industry, it could be said that they act in a field well known to them. Whenever it is possible to envisage a complete reaction - this is one of the main difficulties - this family of processes will be preferred. It results in a relatively light investment, contingent on having good knowledge of the reactions, which assumes:

- as complete an indentification as possible and numerous storage points so as not to denature the quality of the products.
- possibilities of experimentation, i.e., an important laboratory with confirmed technicians.
- staff well trained in handling products which can be dangerous.

Recuperation is sometimes possible, it consists in chemically extracting the valorizable materials from the refuse.

The triumph of the physical-chemical process is when the different refuse products neutralize each other. This operation alone would warrant the existence of such centres, the only ones capable of bringing together antinomic pollution, so as to cancel it.

2. Genesis of the Limay Centre

Since 1945, the "Société d'Assainissement Rationnel et de Pompage" (SARP) provides a public service, within the general line of the CGE group, specialized in the field of industrial drainage. The following may be particularly mentioned:

- maintenance of sewers
- cleaning, clearing of main drains, ponds and other lagoons

- removal of pumpable waste
- industrial cleaning (notably tank bottoms) and removal of the corresponding sludge
- scaling and maintenance of piping
- transport of fluids, removal of liquid and pasty refuse
- pumping of drilling mud or sludge from sewage farms
- more generally speaking, all works in an insalubrious environment.

Chiefly installed in the greater Paris area, but with branch units all over France, it employs at present some 600 people.

The experience acquired over the years has provided it with great knowledge of industrial refuse, especially the pumpable refuse and the dangers that they may offer in case of wrongful dumping, hence the necessity of finding for most of them, solutions more complex than dumps, even if carefully determined and operated. To this was added the concern to valorize them as far as possible. For this purpose, in 1973, the SARP performed precise studies in view of constructing a treatment centre, jointly with the Omnium d'Assainissement, a "sister" company being part of the same financial group. This study was performed in close collaboration with the corresponding authorities notably the Agence de Bassin Seine-Normandie and the Service des Mines, "classified establishments" department. In this way the Limay Centre was born. The management of this centre was entrusted to a joint stock company "SARP-Industries", formed in July, 1975 for this purpose. Its installation in the greater Paris area (60 km to the west of Paris) should limit as far as possible the costs of transport, which are heavy even for refuse.

At the start, SARP Industries contained four separate departments:
- Physical-chemical treatment to neutralize liquid, acid or basic refuse, reduction of the hexavalent chrome, with a vocation to extend as far as possible to liquid effluent whose toxic elements might be precipitated.
- Incineration of liquid organic refuse whose LHV and physical characteristics (notable content of matter in suspension) were compatible with a relatively light installation.

- Decyanization.
- Insolubilization or fixation of sludge.

Subsequently, in view of the demand from industrialists, being itself subsequent to the increased requirements of the law covering refuse, three new sections were installed:
- Elimination of laboratory refuse.
- Treatment of water-hydrocarbon mixtures in solution or emulsion.
- Treatment of ammoniaco-cuprous liquids.

These two latter lines were designed in view of recuperating as much as possible of the interesting by-products.

Rapidly the level of activity of SARP-Industries placed it in the leading rank of treatment centres given that in 1978, 86,000 tons of refuse were treated at Limay whereof 36,000 tons of mineral liquids, 17,500 tons of incineratable refuse, 26,500 tons of sludge and 6,500 tons of soluble oils.

This centre is an excellent example of adaptation to the requirements of a constantly evolving market. At the time of writing, it employs 60 people, 8 of them in the laboratory which plays both a part of regulator and research.

THE NETHERLANDS

Waste Treatment by AVR

By: M. J. Kleinjan
N.V. Afvalverwerking Rijnmond
Waste Disposal Colloquiem,
March 23, 1982

WASTE DISPOSAL COLLOQUIEM, MARCH 23, 1982

Waste Treatment by AVR - Introduction

Waste is a result of activities of man. This is true for all kinds of waste, such as waste deriving from his personal life, his being a part of a community, and from all industrial activities that support the community. In times of prosperity and abundance, the flow of waste reflects that situation, like it does in difficult times, when goods are expensive and scarce. This implies that also comparable events can be seen through the history of dealing with industrial waste and with the more matured - at least this is what one would expect - disposal of municipal waste. The municipal incineration plant of Rotterdam started in 1912.

The Rotterdam industrial area ("Rijnmond") developed after the Second World War into the strongest industrialized area in the Netherlands. At the same time this area has one of the highest population densities in the Netherlands. In the first years of industrial growth, little attention was paid - and not only in the "Rijnmond" area - to the consequences of it for the environment. Waste was not yet recognized as a problem. With the continuation of industrial development, along with increasing population and air-, water-, and soil pollution, it was realized that the waste problem needed to be looked at in a wide perspective to ensure the maintenance of a proper and healthy environment. This implied that for an adequate environmental control, including the disposal of wastes and refuses, rules and legislations had to be established. The national government recognized the importance of a national environmental control policy. This resulted, amongst other things, in the institution of the "Ministry of Public Health and Environmental Hygiene" in 1971.

The Dutch authorities are getting more and more grip on the situation by initiating various environmental legislation acts.

Just to mention a few important ones:

- the Air-Pollution Act,
- the Surface-Water Pollution Act,
- the Chemical Waste Disposal Act from 1979 and the even more recent "General Waste Materials Act",
- the General Environmental Hygiene Regulations Act with the purpose to co-ordinate all relevant acts.

Of course rules and regulations are essential, but if the right tools to enforce implementation of them are not available, the practical result of those regulations may be very marginal.

The AVR: In General

The "N.B. Afvalverwerking Rijnmond" ("Rijnmond" Waste Treatment) started officially on April 1, 1973. The AVR has been set up to incinerate, in full, continuous operation (24 hours, 7 days per week), municipal-, industrial- and chemical waste, on a non-profit basis in an efficient, safe and environmentally proper way. The heat generated by the combustion process is used for the production of steam, which is passed on to turbogenerators to generate electricity. The quantity of electric power generated is sufficient to meet the energy demands of a town with approximately 70,000 inhabitants. Part of the steam is used for the production of high quality process and boiler by distillation of water from the river. Annual capacity of the AVR installations allows that more than 800,000 tons of waste can be processed. At this moment, 180 million Kwh electric energy and 6 million m^3 distilled water are being produced per year.

At present, the company is a N.V. (Ltd) with ownership changing hands from Rijnmond communities to Rotterdam. All vote-holding shares are being transferred to Rotterdam. If all financial and legal hurdles can be taken, AVR will finally become one of the Rotterdam municipal services.

AVR Installations

Chemical Waste Incineration

One rotary-drum chemical waste incinerator with an annual capacity of 34,000 tons. This unit can handle most types of chemical waste, but has no heat recovery facilities and only inadequate treatment of fluegases.

For the processing of chemical waste, the AVR has one special rotary-drum furnace. It is the only one of its kind in the Netherlands. Two identical furnaces were put into operation in 1973 and were considered most up-to-date at that time. After all rebuilds, only one unit is left over and operational today. Compared to the present state of technology, it must be said that although the furnace technically performs well, its concept as a whole must be regarded as inadequate.

Within the requirements for a proper environmental control, only a limited range of chemical waste can be accepted. Besides these environmental limitations, the processing capability is also too small and there are no facilities for energy recovery installed.

In 1981, 34,000 tons of chemical waste - originating from all parts of the Netherlands - were processed. This is far over the design capacity of 23,000 tons and close to the maximum feasible capacity. However in the Netherlands substantially more chemical waste is being generated, which needs proper disposal.

Electricity

Three steam turbine electricity generators, with generating capacity of up to 55 MW. Maximum annual output of 275 million Kwh.

Water Evaporation

Three water multi-stage evaporation units for industrial boiler and process water. Each unit has a capacity of 520 m^3/hour. The total annual capacity is 10 million m^3.

A close relationship between the amount of waste and the prosperity level is clearly shown by the (low) figures during the crisis of the 30's, the period of the two world wars and the economic recession around 1957. Also the Korea crisis and the oil crisis can be distinguished in the graph.

Figure 2 also shows, this time for the period 1961 up to and including 1978, how closely prosperity level and waste generation are related to each other.

Over Capacity Problems

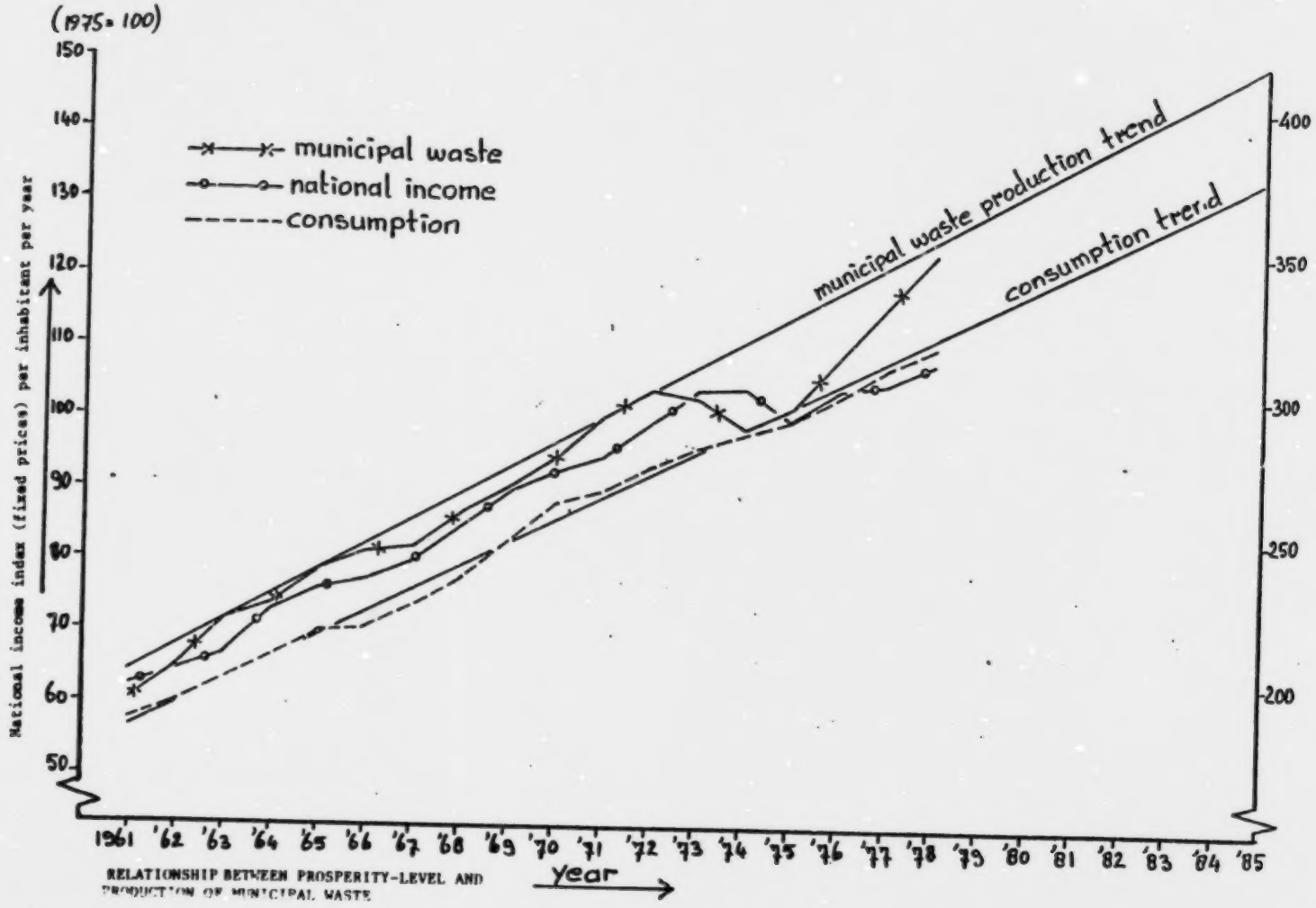
When planning the required capacity of the AVR installations, it was assumed that 440,000 tons of industrial waste from the Rijnmond area would be available, consisting of 292,000 tons of waste from existing industries and almost 200,000 tons from new industries or expansion of existing ones. From this amount, it was expected, roughly 440,000 tons would be delivered to the AVR combustion furnaces.

Actual practice, however, was bitterly disappointing. In 1974, total deliveries remained far below 100,000 tons. What were the main reasons for this?

The production of electric power and distilled water has increased considerably during the last few years. Distilled water production increased from 2.4 million m^3 in 1974 to 5.9 million m^3 in 1981. In 1974, 42.7 million Kwh electric power was generated as compared to 165.9 million Kwh in 1981.

Getting Rid of Waste

This, in fact, brings us to a main problem, that the AVR has struggled with since start-up. The ordinary dumping, or getting rid of waste "in some other way" is, at least in the short term, cheaper than having it dealt with in a proper way. In the long-run, however, also in our waste disposal world, "penny-wise" turns out to be "pound-foolish".



RELATIONSHIP BETWEEN PROSPERITY-LEVEL AND PRODUCTION OF MUNICIPAL WASTE

Profits/yield

x Dfl. 1,000,–	year 1973 (3/4 year)	1974	1980
processing income	2,940	8,377	50,800
government subsidy chemical area	–	–	3,000
water energy sales	1,992	1,539	16,000
costs	22,737	36,151	69,800
loss	17,805	26,235	–0–

figure 3

chemical industry 's turnover (in billions of D fl.)

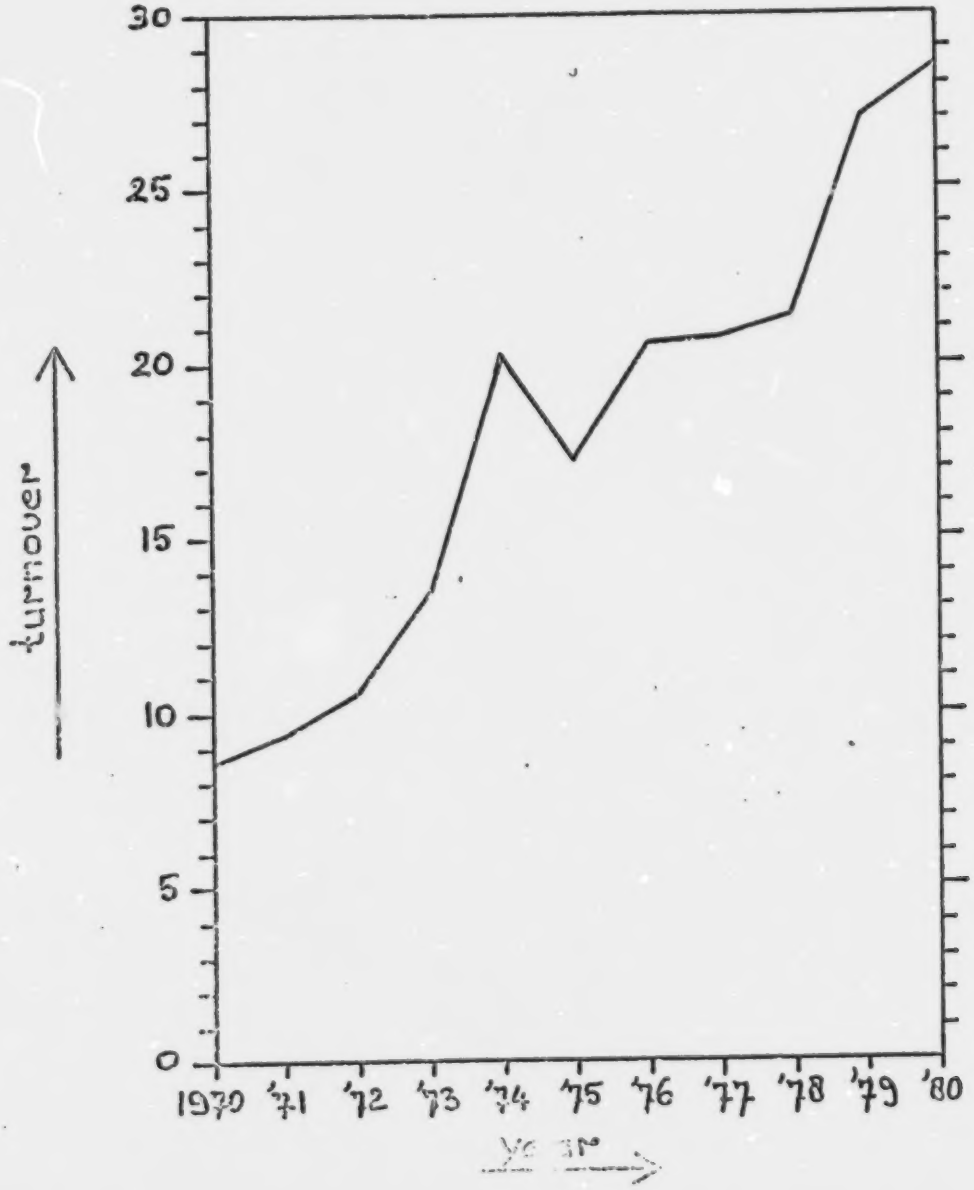


figure 5

Just consider the contaminated soil from the community of Lekkerkerk that had to be excavated and processed at the cost of much more than Dfl 100 million. It is the society as a whole that has to pay this penalty. The people responsible for past dumpings cannot be traced. With regards to this, it seems evident that big question-marks should be placed at the dumpings of waste in Belgium. It goes without saying, that what is bad for the Dutch environment cannot be healthy for the environment of our southern neighbours. The question arises whether this form of "nuisance to a neighbour" should not be stopped as soon as possible.

Conclusion

Government Influence

Finally I would like to end my lecture by looking into the future with regard to waste disposal in the Netherlands. You will have noticed that I am all in favour of a centralized handling of waste under strict government control.

It is evident that we consider this a government task. A comprehensive and proper maintenance of our living environment is in the interest of all of us. That is why the government also in the future should have a strong directing influence, to prevent that the economically attractive waste is taken out of the total package by interested parties, leaving the real problem waste for the society to dispose of. Problem waste that in that case can only be processed against extremely high costs, leaving expensive installations with a huge over-capacity, which costs have to be carried by our community. Optimal efficiency in waste disposal can only be reached when the processor has the disposition of a balanced package of waste. This is the more important, since with the economic recession, the amount of waste also decreases, while at the same time the caloric value of it has a tendency to decrease over the years. Processing costs, however, following the general trend, keep increasing.

That strict government control of the channelling of waste-streams is important, hardly needs further explanation. That many uncontrolled waste-streams have caused a lot of troubles during the recent years is clear. But at the same time, I would like to urge that the authorities, when issuing environmental rules and regulations, maintain good communication with the industries, so that policies and practices will be compatible, leading to beneficial results for all of us.

Planning of Processing Capacity

Another aspect that will play an important role inthe future, is the planning of processing capacity. When planning additional processing installations, I think particularly of installations to handle municipal waste, thorough consideration needs to be given to the historical relation between prosperity level and waste quantities. If this is omitted, we will soon face an over-capacity in this country, with financial disasters resulting from it.

Where the Uniser tragedy is still fresh and every party involved in disposal of chemical waste is determined not to let it happen again, we have to move fast. Planning and building of facilities requires time -- 1½ years for a physical-chemical treatment plant and 2½ years for a new incineration unit.

Chemical industries are being tempted to bring their waste cheaply to Eastern Germany, where chemical waste, as much as 80,000,000 tons, is eagerly awaited in exchange for D-marks. Hardly any restriction is made for the acceptation of this waste, everything goes, soluble, cyanides, chromates, organic compounds, refinery residues, etc.

Other representatives of unknown nations are visiting us with attractive ideas.

We feel it is irresponsible to do elsewhere what we don't accept in our own country. Let's make it right as soon as we can. The Dutch government has to accept this responsibility and should act accordingly!

U N I T E D S T A T E S

Closure and Remedial Activities
at Hazardous Waste Sites

By: Rollins Environmental Services Inc.
Deer Park, Texas

INTRODUCTION AND CONTENTS

This report explains the services available from the Rollins Environmental Services (RES) Field Services Group. The report attempts to capture the unique strength of the RES organization and the evolution of the Field Services Group to present expertise in closure and remedial activities at hazardous waste sites.

Information is organized and presented under the following headings:

Field Services - Capabilities Summary

Field Service Expertise

Selected Project Summaries

- Impoundment Projects
- Drum Sites and Special Projects
- Specialized Equipment

Technical and Operating Expertise

General Brochure - Hazardous Waste Management Services

FIELD SERVICES - CAPABILITIES SUMMARY

The purpose of this report is two-fold:

A. Eliminate an identity problem of the Rollins Environmental Services (RES) organization.

B. Capture and outline the capabilities of the RES organization in the general area of assessment, conceptual design, and turn-key project management of remedial work at hazardous waste sites.

A. RES is often thought of as the firm to call for transportation and disposal of hazardous waste, particularly the more difficult materials requiring high temperature incineration. RES is seldom recognized as one of the few firms with significant project design and execution expertise in the area of remedial action or closure of hazardous waste sites.

In fact, the general association with the waste disposal industry often presents an identity problem when potential clients are looking for technologically, sophisticated environmental or engineering firms for the design, engineering, or management of a hazardous waste project. Since many of the larger abandoned or improperly designed sites are a product of past land disposal activities by firms touting recovery, high technology, environmentally secure sites, etc., it is easy to understand some of the skepticism regarding the waste disposal industry.

There is a basic difference between RES and the rest of the industry in the development and use of technology. Land disposal firms simply have had no significant requirement for technical personnel. During the past ten years RES has concentrated on the development of three high technology integrated waste treatment facilities. Details of the corporate and technical evolution of the RES organization is outlined in the last section of the report.

This report attempts to capture the technical orientation and accomplishments of the RES organization. Hopefully, this information will capture the unique RES contribution to the waste disposal industry and minimize our identity problem.

B. The general technical thrust of the organization has been carried into all conventional areas of hazardous waste disposal.

This ten year evolution of incineration, biological and chemical treatment methods, and the original design of a seventy foot deep moving face landfill for bulk chemical waste provided a strong base

for off site remedial work. The Field Services Group was organized to apply this inhouse RES experience and technology to off site projects.

The RES (TX) Field Services Group has completed over twenty-five (25) major projects with extensive experience in closure of impoundment or bulk type projects. The RES (NJ) Field Services Group has extensive experience in the drum or containerized type projects. The typical project experience of both groups is included in the Project Summary Section.

A careful review of this report will indicate that RES is one of the few organizations with true experience in the following areas:

1. Project Assessment - Personnel with project execution experience utilizing specialized equipment are available for the representative sampling of impoundments including bottom soil sampling capability. This allows quantification of multi-layered components and total contents including soil contamination. Detailed analytical results including special emphasis on the physical properties are examined to determine the various physical handling options. Access and physical layout of job-site is documented for detailed project planning.

2. Conceptual Design - Both the assessment and conceptual design phases are executed by the same project team consisting of a project manager, a technical manager, and a field superintendent all with substantial project experience. Using cost and experience data from past projects and the data generated in the assessment phase, various alternative approaches to the project are generated. This conceptual design activity includes the examination of special equipment design that can impact project cost and execution. This phase results in a report that makes specific recommendations on the various approaches to the project. Outlined for each alternative is detailed discussions of how to do the job, sequential activities, type and sizing of equipment, activities by day, total project time, and estimated cost for each activity. This report, based on extensive hands-on project experience, is the logical starting point for the detailed engineering and design phase.

3. Turn-Key Project Management - RES has routinely been doing the assessment, design and execution of major projects for the past five years. This expertise is available as a total package to manage the overall project investigation and design utilizing the necessary disciplines from outside consulting or engineering organizations. RES also will assume complete responsibility for project assessment, design, and field execution.

The RES experience has been that the high technology approach has often reduced total project cost by 30-40% over conventional methods.

Project approaches by engineering firms without hands-on project execution experience specify costly contingency measures to cover their unknowns. A small RES project team can routinely deliver an assessment-design report within 3-4 weeks that eliminates the mystery and provides innovative project approaches and equipment design. Engineering is then minimized and assumes its proper function of selecting the best conceptual design alternatives, cost comparison, refinement, and specifying the optimum alternative. Engineering-consulting firms, site owners, generators, government agencies, law firms--anyone interested in the RES approach should make the RES Field Services Group the first contact regarding a hazardous waste project.

RES (TX) FIELD SERVICE EXPERTISE

The unique capabilities of the RES Field Services Group in the area of remedial site work is a result of two factors.

1. The general technical thrust of the organization has been carried into the development of secure landfill technology. This same technical approach has been incorporated in the development of the Field Services Group which has extended and expanded overall corporate waste handling technology into off-site work.

2. Field Service activities have been centralized by specialty into two general project types - impoundment and drum. Therefore, each type of project is administered by a specialized group. This has allowed specialized staffing and on-going refinement of skills, equipment and techniques in the evolution of a technical approach to remedial work.

The RES organization has evolved as a technically oriented group. For example, forty-five (45%) percent of all RES (TX) employees hold technical degrees. The Field Services Group was organized to apply RES technology to off-site hazardous waste projects. This group has been developing state of the art approaches to off-site hazardous waste management projects with the same technical thrust of the overall RES (TX) organization. Geographic location in the heart of the Gulf Coast refinery, chemical, and petro-chemical processing complex has provided specialized experience in the bulk handling of toxic chemical wastes, sludge, and hazardous residues.

The process industries have been generating extremely large hazardous waste streams for many years. The routine handling of these waste streams has been as bulk versus drum waste. The wastes are stored and processed through earthen impoundments, pits, ponds, lagoons, etc. The size of the impoundments range up to many acres in size and contain huge quantities of liquid, solids, viscous sludges, semi-solids in mixtures, solutions, layers, etc.

For years the process industry has required clean out maintenance, or closure of these large waste impoundments. The technical orientation of RES (TX) and the central location in the Gulf Coast complex has provided an unusual opportunity to develop technical approaches to large scale hazardous waste projects. As a result of this experience RES (TX) is the leader in the high volume capital intensive approach to large hazardous waste projects. The high volume approach has required that significant expertise be developed in the early project assessment, definition, evaluation, design, engineering, and planning stages.

The Field Services approach is based on the heavy hands-on experience from the operation of RES (TX) integrated waste disposal facilities. At this site, RES (TX) has comprehensive technical and engineering expertise in all the commercially feasible hazardous waste disposal

methods (except for deep-well injection). The ten year development of this integrated waste disposal facility has been accomplished by RES (TX) Inc. personnel and reflects the latest economical state of the art hazardous waste disposal methods for:

1. Incineration: High volume commercial incineration of highly chlorinated hydrocarbons, PCBs, toxic chemicals, pesticides, cyanides, phenols, high sulfur organics, and waste water streams are routinely processed as solids, liquid, or semi-solids in a 100 million BTU/hr system. RES (TX) Inc. personnel have designed, engineered, and installed the automated monitoring and control systems necessary for the U.S. E.P.A. permit for PCB incineration.

2. Secure Landfill: Hazardous organic and inorganic compounds are routinely processed and landfilled. Development of chemical solidification methods for organic waste allow the unique operation of a 50 ft. deep moving face landfill and ultimate disposal of 2.8 million YD^3 of hazardous waste in a 35 acre secure landfiil. RES (TX) Inc. personnel developed technology for: surface water control, ground water control, leachate collection system, waste water treatment system, and the related civil-chemical engineering expertise for landfill operations and closure.

3. Chemical-Biological Treatment: Routine waste streams are processed through chemical neutralization, precipitation, destruction, coagulation, flocculation, activated sludge, clarifiers, etc. Effluents can be incinerated, landfilled, land farmed, deep-well injected, or discharged with NPDES permit.

4. Transportation: Hazardous waste including PCBs, are handled by company operated equipment, such as: vacuum trucks, dump trailers, bins, bulk trailers, vans, high pressure vinyl chloride monomer trailers, and Ram-E-Jec sludge trucks.

During the five year period ending February, 1981, RES (TX) Inc. processed the following hazardous waste volumes:

Incineration	- 350,893,000 Pounds
Landfill	-1,124,568,000 Pounds
Biological Treatment	- 336,975,000 Pounds
Chemical Treatment	- 27,971,000 Pounds

These activities required the characterization of more than 6,000 individual waste streams and actual disposal of over 2,500 waste streams.

No other organization in the United States has the expertise of RES in the areas of hazardous waste incineration, secure landfilling, deep-well disposal, and specific expertise in the transportation, materials handling, and analytical functions necessary to support a technical approach to the hazardous waste disposal business. This experience base has allowed a technically oriented Field Services Group to extend and expand this unique experience into off-site hazardous waste project work.

SELECTED FIELD PROJECT SUMMARIES

Conceptual design for field projects, plant processes, landfill design, waste handling, and all phases of the present RES operations has been developed internally. This technical expertise is available to engineering and consulting firms, construction companies, site owners, waste generators, government agencies, law firms, or anyone concerned with hazardous waste projects.

IMPOUNDMENT PROJECTS

1. Pacific Northwest - Mercury Waste Lagoon - Turn-key assessment, conceptual design and job execution for the excavation and chemical solidification at site of 10,000 cubic yards of mercury contaminated sludge. Transportation and disposal handled by generator. Required constant mercury vapor monitoring. Project presented unique operational problems due to location on a body of water with excavation bottom 13 feet below sea level. Porous levees and bottom required bulkhead construction techniques, continuous water removal and would not allow equipment operation within the excavation. Site backfilled for plant expansion.

2. Texas - Tenant abandoned 8.5 acre site after heavy contamination with arsenic pesticide manufacturing waste. RES Field Services Group retained as consultant for conceptual design and implementation of site assessment which required development of soil sampling and analytical methods acceptable to Texas TDWR, Harris County Pollution Control, and the former tenant's legal counsel. RES interface with client's legal counsel was successful in negotiating an out of court settlement from former tenant and state approval for closure method. RES designed, executed, and interfaced with state during complex project closure which required, surface water control, removal of 14,000 cubic yards of contaminated soil, treatment, testing, and discharge of 500,000 gallons of run-off water. Rapid field soil testing methods developed for excavation depths ranging from six inches to fourteen feet. Project included contouring, backfill, and finish grading.

3. Houston - Petrochemical Sludge - Assessment, conceptual design and execution of site closure of two (2) lead contaminated sludge ponds. 34,000 cubic yards of waste sludge phase separated for deep-well disposal and chemical solidification at Class I landfill. Backfilled 45,000 cubic yards, site closed, contoured, finish graded and landscaped. Project problems included large surface area - shallow excavation over a perched aquifer. Excavation was required around several high pressure gas lines that passed through the site. Required unique excavation and backfill approach to minimize equipment operation in "quicksand" environment. Total project completed in 26 days meeting tight November 19, 1980 deadline.

4. Houston - Periodic Cleanout and Closure - Calcium Carbonate/Sulfate Lagoon - Assessment and conceptual design of a successful dewatering method for separation of brine from waste sludge. Brine returned to generator and 9600 cubic yards of sludge chemically solidified at site prior to transport to Class I landfill. Limited heavy equipment assess was solved by utilizing solidified sludge as a ramp into the excavation. Two cleanouts and final closure were executed during 24 month period.

5. Houston - Closure - Herbicide Waste Pit - Assessment, conceptual design and execution of unique high volume sludge pumping, excavation, transportation and Class I landfill disposal of herbicide waste from manufacturing process. Total of 90,000 cubic yards waste sludge separated into liquid phase, wet sludge chemically solidified at site, dry sludge transported in original form. This project required the design of a large remote controlled barge mounted sludge pump for high volume standpipe loading of bulk vacuum trucks. Project problems included unstable dike which required design and operational scheduling to minimize hydrostatic pressure. Site was capped, final graded and landscaped.

6. Illinois - Railcar Waste Lagoon - Assessment, conceptual design, and job execution for site closure of waste residue from railcar cleaning facility. 1600 cubic yards of waste were phase separated, pumped, chemically solidified at site, transported, and landfilled at Class I landfill. Project problems included limited equipment access and unstable alluvial deposit soil conditions.

7. Houston - Cleanout - Isocyanate Polymer Impoundment - Assessment, conceptual design, and job execution for excavation, transportation and Class I landfill disposal of approximately 1000 cubic yards of waste sludge. Partial chemical solidification on-site and balance at disposal site.

8. Houston - Site Closure - Calcium Sulfate/Chrome Pit - Turn-key assessment, conceptual design, and job execution for the chemical solidification, excavation, transportation and Class I landfill of 6000 cubic yards of waste sludge. Project required road stabilization through swamp, high viscosity pumping,continuous testing program, on-site solidification and closeout including backfill, final grading and landscaping.

9. West Texas - Railcar Waste Lagoon - Assessment, design, and project execution of the cleanout of 1500 cubic yards of residue from railcar cleaning facility. Liquid phase pumped to bulk transport, balance chemically solidified at site and waste transported to Class I landfill. This project was completed during weekend plant turnaround. Special problems included extremely poor equipment access, substantial solid residue, and 400 mile transport distance. Special backhoe strainer bucket was designed for the project.

10. Houston - Cleanout - Isocyanate Sludge Pit - Assessment, design, and job execution for excavation, transportation, and Class I landfill of 8000 cubic yards of waste sludge. Liquid phase separated on-site, pumped into bulk transports, and chemically solidified at Class I landfill. Site problems included limited access and poor soil support conditions. Project included stabilization of the work area for truck and heavy equipment traffic, high volume pump loading of bulk tankers with standpipe, partial chemical solidification on-site with balance at disposal site to reduce transportation cost.

11. Houston - Petrochemical Sludge - Assessment, conceptual design, and job execution for phase separation on-site of contaminated petrochemical sludge. 300,000 gallons of liquid phase pumped and transported to Class I deep-well. Balance of 1500 cubic yards of sludge transported to Class I landfill for solidification and disposal. Project required phase separation, complex analysis and characterization of several priority pollutants, and required significant hand labor.

DRUM SITES AND SPECIAL PROJECTS

These projects are more labor intensive in nature than the impoundment projects and require significant planning for personnel protection. Safe job execution requires experienced personnel for in-field assessment and problem solving.

1. Alabama - Field repackaging of over 12,000 drums of hazardous waste for safe transportation to an approved disposal site. Project required documentation and clean up of three sites.

2. New Jersey - Project was a turnkey waste identification, repackaging, transportation, and disposal project for the state of New Jersey. Approximately 500 drums of miscellaneous unknown wastes has been abandoned in a junkyard. RES analyzed the waste in ordger to group, repackage (as necessary), remove, and transport the waste to a secure disposal site. The project included decontamination and clean up of the site.

3. Alabama - Excavation, transportation and disposal of over 9,500 cubic yards of soil contaminated with arsenic and cyanide.

4. New York City - Turnkey project clean up of a pesticide storage facility for the city of New York. RES analyzed, repackaged, transported, and incinerated over 125 drums of solid waste pesticide and 4,000 gallons of miscellaneous liquid pesticide. Pesticides included DDT, Malathion, and 2,4,-D.

5. Pennsylvania - Project required the sampling, analysis, transportation, treatment and final disposal of over 2,500 drums of unknown hazardous wastes and the decontamination of 5 tank trailers at the abandoned Wade Site in Chester, Pennsylvania.

6. Elizabeth, New Jersey - RES was one of the two major contractors involved in cleaning up the 70,000 drum Chemical Control Site in Elizabeth, New Jersey. RES was primarily responsible for sampling, analyzing, transporting, and treating liquids from the site.

7. State of New Jersey - Several other clean up projects have been completed for the state of New Jersey DEP including the Atlantic Recovery (approximately 1,000 drums) and El Cid (approximately 85 drums) projects.

8. Pittsburgh, Pennsylvania - Project involved the decontamination of a major electrical unit and the repackaging of PCB capacitors for disposal.

9. Richmond, Virginia - Project required excavation and removal of pressurized cylinders of phosgene and borane.

10. Philadelphia, Pennsylvania - RES provided turnkey service to an electrical contractor for the disposal of six large PCB transformers. PCB liquids were collected in bulk for transportation and incineration. The drained units were transported for final disposal in compliance with 40 CFR 761.10.

11. Maryland - Project completed for the U. S. Coast Guard (Fifth District). Activities centered around (1) the recontainerization of PCB contaminated liquids from bulk tanks to 55 gallon drums and transportation to a government storage facility at Curtis Bay, and (2) the removal of flammable liquids from tanks to tankers for transport and ultimate incineration of 34,500 gallons of PCB materials.

SPECIALIZED EQUIPMENT

Special equipment design is routinely considered for each project. Each of the pieces of equipment listed below have been developed as a result of this activity.

1. Field Service Project Van - Design, engineering and construction of self-contained 40 foot van for field projects involving hazardous or toxic waste. Van contains: showers, change room, outside safety showers, laboratory, complete first-aid, air support systems, and repair shop. Equipped for 480, 240, or 120 volt service. Van is designed for toxic waste projects in remote areas with self-contained kitchenette, air-conditioned office and laboratory.

2. Field Service Barge Pump - Design and engineering of high volume remote controlled sludge pump for hazardous waste. Remote diesel-electric generator and controls operate mobile pontoon mounted explosion proof pump for operation in corrosive, hazardous or toxic environments of waste lagoons. Pumping rates of 500-1000 gpm on high viscosity sludges.

3. Pontoon Derrick Barge - Design, engineering, and construction of 8' X 18' pontoon barge to support sampling and assessment activities in hazardous waste environment. The barge is equipped with a 20' derrick and specialized sampling equipment to allow extensive multi-layer sludge and bottom sampling with casing or core sampling techniques. The barge is cable controlled and can be winched over solid or semi-solid surfaces.

4. Sludge Separator - Design, engineering and construction of specialty piece of equipment for separation of sludges into pumpable and non-pumpable fractions. The separator allows the use of conventional excavation equipment for bulk loading or transfer.

5. Several smaller devices have been designed for specific projects. Dragline clean out buckets, backhoe rakes, wheel mounted slip buckets, etc. have been utilized to simplify project execution and significantly reduce total project cost.

TECHNICAL AND OPERATING EXPERTISE

Rollins Environmental Services (TX) Inc. is a wholly owned subsidiary of Rollins Environmental Services Inc. (RES). RES also owns Rollins Environmental Services (LA) Inc., and Rollins Environmental Services (NJ) Inc. Each of the companies operate as independent regional entities with corporate officers and management in the Wilmington headquarters office. The parent company, RES Inc. is a wholly owned subsidiary of RLC Corporation. 1980 RLC sales revenue exceeded $350,000,000. The environmental service companies accounted for $31,000,000. Matlack, Inc., the largest tank truck carrier in the United States, accounted for $204,000,000 in sales and Rollins Leasing Corporation, one of the five largest truck leasing firms, generated sales of $113,000,000.

Rollins Environmental Services operates a commercial hazardous waste incinerator at each of the regional locations: Deer Park (Houston), Texas, Logan, New Jersey and Baton Rouge, Louisiana. RES has been in the hazardous waste incineration business for more than ten years with three of the four large scale commercial hazardous waste incinerators in the United States operated by RES.

Commercial scale incineration systems do not exist as off the shelf items. The systems have all been designed, engineered, and constructed by RES. This technology is the result of ongoing state of the art evolution that is not readily available to other firms or outside equipment manufacturers. Based on the ten years experience in the development and operation of three hazardous waste incinerators, RES has more experience in this area than anyone in the United States. Continual upgrading is a regular ongoing activity at each facility as the state of the art expertise continues to grow.

The nature of the incineration process is much more technically oriented than other waste disposal methods. Since incineration was the initial activity of RES, the entire organization has evolved with a strong technical orientation. The operation of an incineration facility is typical of the general operation of a refinery or chemical processing unit:

1. Hazardous, flammable, explosive, or toxic feedstocks are processed, handled, and transferred in large quantities requiring detailed safety programs and operating procedures that must be well conceived, implemented, and followed by everyone.

2. Operation of a high risk capital intensive, continuous 24 hour per day/ 365 day per year process requires a more rigorous and well conceived management approach than any other waste disposal activity. Many skilled technicians are required along with skilled supervisors at all levels of the organization.

3. Effective communication and coordination between transportation, operation, quality control, technical, and sales departments must take place easily.

4. Intimate awareness and appreciation for the requirements of OSHA, EPA, DOT, and other federal, state, and local regulatory agencies is much more complex than most firms outside the chemical or petro-chemical areas.

This involvement with and active development of the present state of the art incineration technology and operations resulted in an organization much more technically and operationally oriented than other firms in the waste disposal business. Operating a business where an explosion or other major catastrophe can be the immediate result of a mistake instills a unique discipline on the organization. Safety programs are taken seriously, emergency drills are a routine part of the business, assessment of risks and developing solutions is a major activity for everyone.

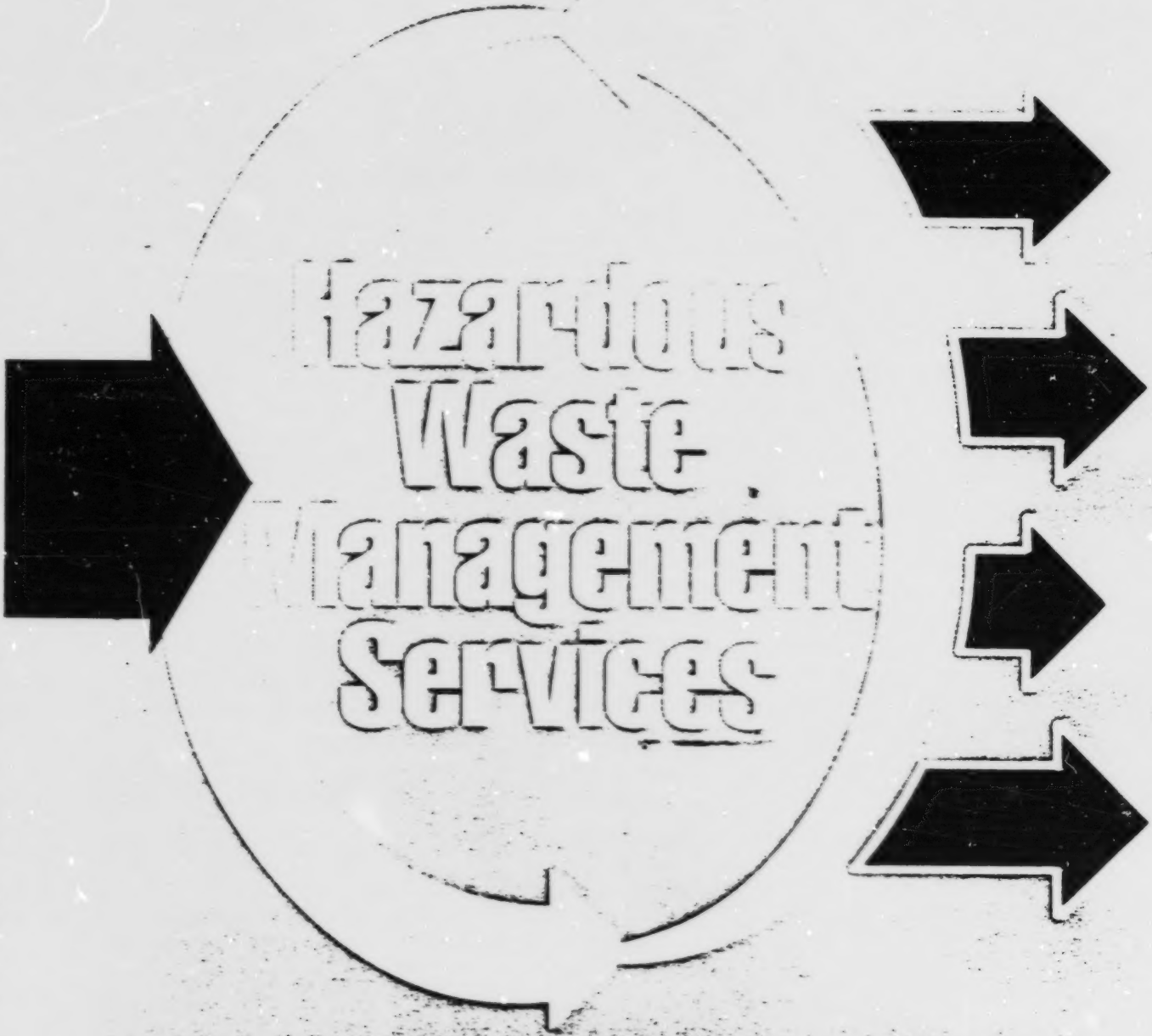
SELECTED PROJECT SUMMARY UPDATE

New Jersey - Closure Plan - A major A & E firm had developed the closure plan for several historic impoundments at a New Jersey hazardous waste site with estimated closure cost of 6.7 million dollars. The RES (TX) Field Services Group was asked to do a secondary assessment and review the closure plan. Based on the RES assessment and revised conceptual design, the estimated closure costs have been reduced to 3.0 million dollars. RES (TX) has been retained as a technical consultant to the site owner to interface with the A & E firm during state approval and execution of the closure plan.

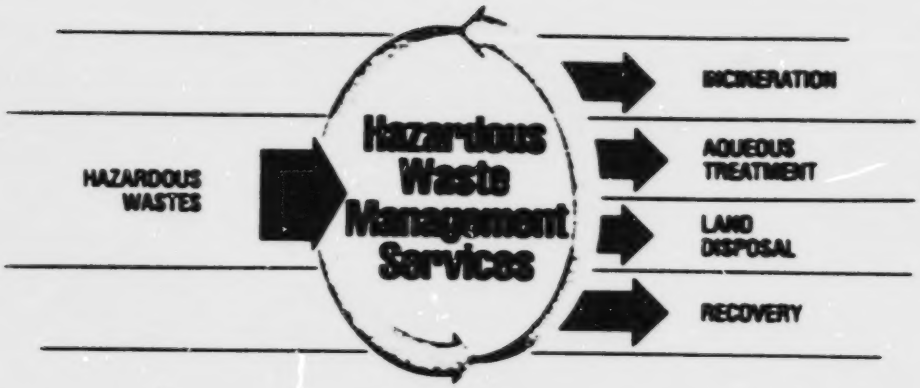
Brooklyn - Closure Plan - A national A & E firm had developed the closure plan for a 100 year old waste site for a major oil company. Complexity of the project due to tidal flux in the ground water and the high population density had resulted in a 1.2 million dollar engineered cost estimate for the closure plan. The RES (TX) Field Services Group assessment resulted in a revised project approach that resulted in actual execution cost of less than 700,000 dollars.

Texas - Closure Plan - RES (TX) was asked to quote on the closure of a PCB contaminated lagoon with landfill disposal in a PCB approved landfill in Alabama. The closure plan was based on the assessment and sampling by a national environmental consulting firm. Using a Thiessen Polygon sampling plan, the RES (TX) Field Services Group was able to identify and segregate the PCB "hot spots" which will require out of state PCB disposal of only 20% of the original waste volume and reduce total project cost by more than $300,000.

Texas - Execution of closure plan for buried drum site. Over 1600 drums of chemical processing waste were exhumed, transported, and secure landfilled. Project required significant infield analytical work to determine the necessary soil and contaminated water for removal and treatment. Project execution including backfill and final grading was completed within 25 working days.



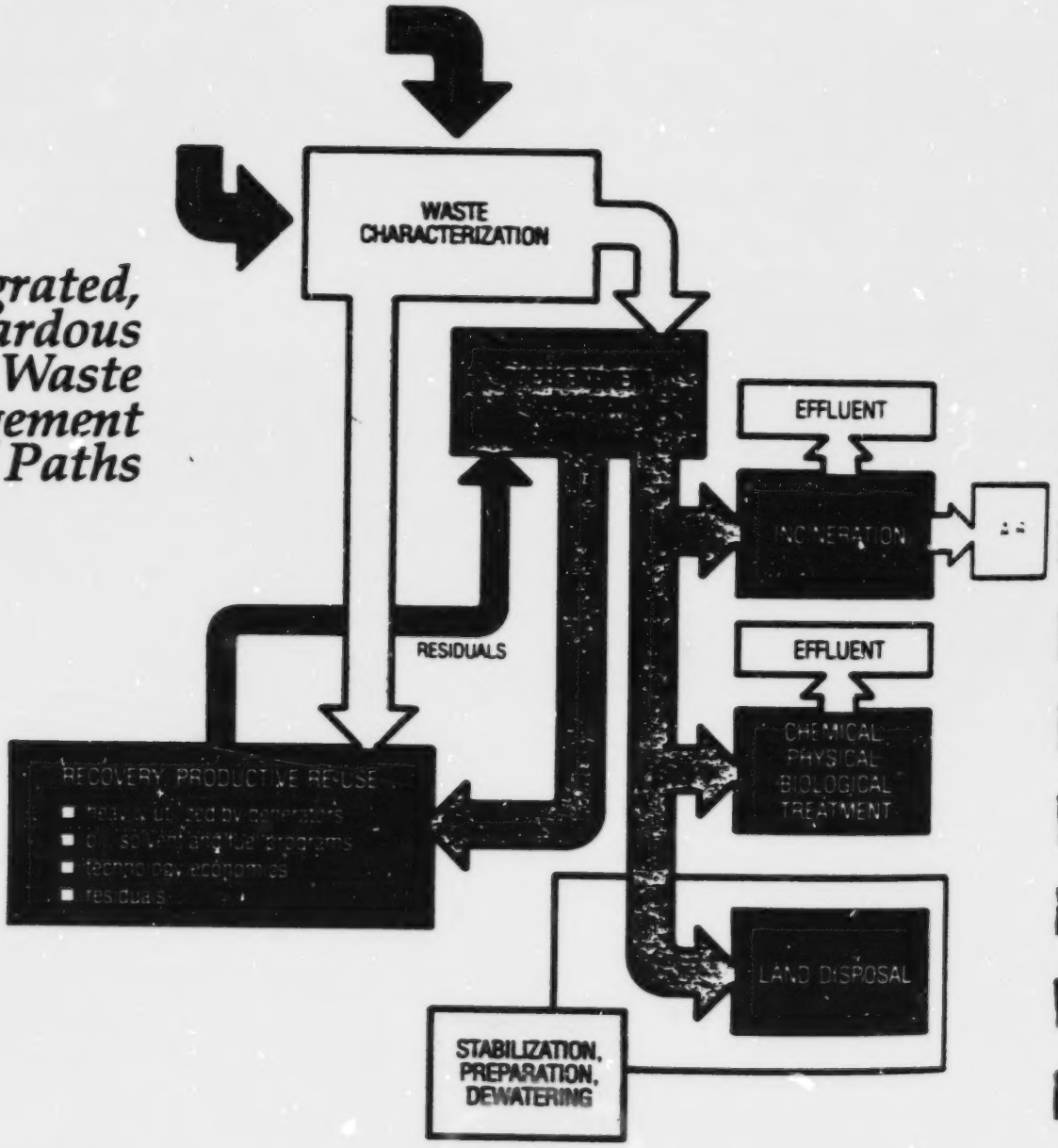
Rollins
Environmental Services



Integrated, Hazardous Waste Management Facilities

Rollins pioneered the concept of regional waste management facilities. And Rollins is the only service company that offers all of the major waste treatment technologies — on a commercially feasible scale.

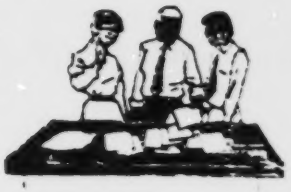
Integrated, Hazardous Waste Management Flow Paths



Rollins' Hazardous Waste Management Services

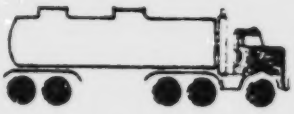
for industrial pits, ponds and lagoons . . . for out-of-service, waste-storage and disposal sites . . . for specialized PCB service and disposal problems.

pages 4-5



Rollins takes title to hazardous wastes when they leave a customer's plant . . . wastes are sampled and analyzed before treatment disciplines are defined and finalized.

pages 6-7



one of the processes employed by Rollins to dispose of chlorinated and non-chlorinated hydrocarbons, pesticides, herbicides, off-spec pharmaceuticals, etc.

pages 6-7

wastes are treated by Rollins to reduce toxicity and to form more stable compounds . . . other wastes are treated by specific biological degradation systems at each Rollins' facility.

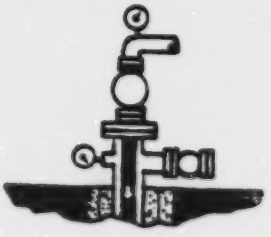
pages 8-9

Rollins operates secure, specially engineered, chemical landfills with leachate collection and ground-water monitoring . . . for disposal of drummed and bulk solids and pretreated sludges.

pages 8-9

some industrial wastes, which don't require extensive pretreatment, or because of large volumes, may be disposed of safely and efficiently by controlled deep well injection . . . at Rollins' truck and barge accessible site.

page 10



for clean-up of pits, ponds and lagoons

Holding ponds or lagoons which are commonly employed to remove solids from wastewater streams eventually fill up. Periodic excavation and site restoration may be necessary to maintain operation in accordance with the Resource Conservation and Recovery Act (RCRA) and the Safe Drinking Water Act.

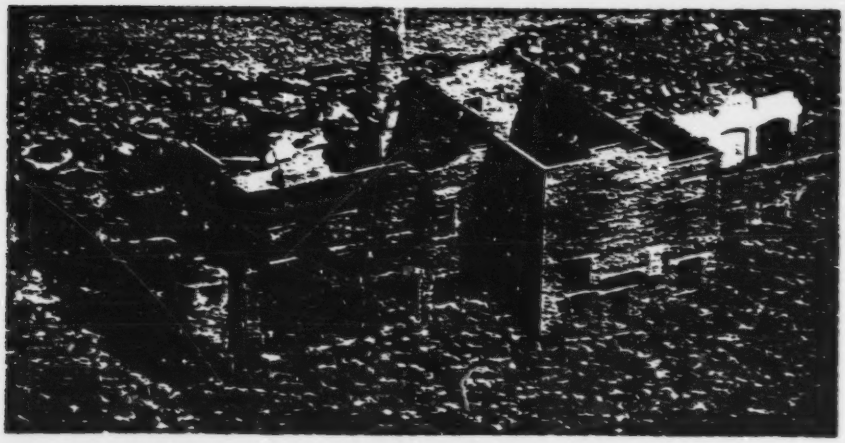
Rollins provides turnkey field services to clean up industrial pits, ponds and lagoons.

After an initial site visit, Rollins develops a comprehensive proposal, outlining the particular specific problems and proposed solutions. Each proposal includes • a detailed physical description of the site • the volume, chemical and physical properties of the pond's contents • recommended alternative solutions • and a detailed cost estimate.

Knowledgeable Rollins technical specialists Providing complete . . . project management . . . turnkey operations . . . on-site supervision . . . transportation . . . reclamation or upgrading . . . coordinated into time frames that make sense.

for abandoned or inactive waste sites

Abandoned or uncontrolled sites where hazardous wastes have been dumped—often improperly or illegally—pose a potential threat to public health and the environment. Superfund legislation mandates that steps be taken to address the clean-up of those uncontrolled sites.



The real and potential problems posed by inactive abandoned hazardous waste sites are enormous. To date, the number of potential hazardous waste sites that have been identified by . . . Of particular concern are those sites where wastes have been stored/disposed of without adequate measures for containing the release of hazardous substances into the environment. The environmental and human damages can be devastating, ranging from direct human exposure, to air, land and surface water contamination.

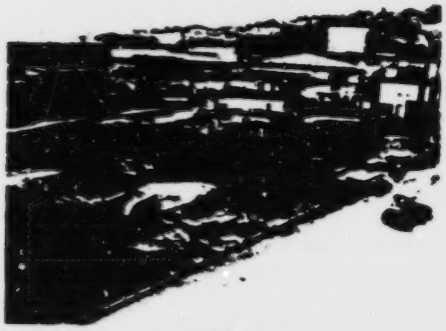
1. Problem definition and project management for turnkey field services.

prior to high-temperature incineration and other treatment disposal methods.

For turnkey field-service projects Rollins provides complete restoration and upgrading of the site for future use.

Restoring access roads to their original condition . . . regrading the lagoons . . . relining the sites for future use . . . or replacing surface-impoundment facilities with alternate waste-processing technologies.

When a project is completed, the Rollins' field-service supervisor will conduct a final review with the customer to compare estimated and actual quantities of material handled; equipment, manpower and transportation utilized; treatment and disposal requirements, and the resulting costs of the overall project.



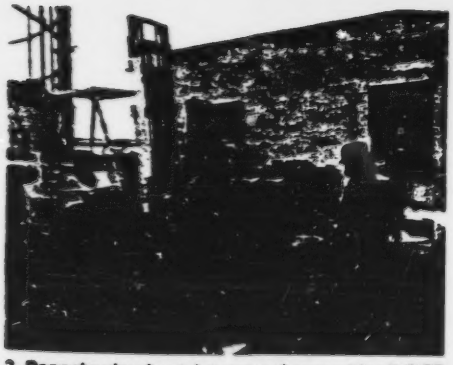
3. Excavation and solidification.

Special Field Services for PCBs

PCBs were banned by Congress in 1976. Since then, an estimated 20,000,000 pounds of oil containing high concentrations of PCBs have been put in storage—awaiting development of proper disposal methods.

In 1981, in what EPA officials hailed as *a major step in dealing with banned industrial chemicals*, the federal government approved Rollins Environmental Services (TX) Inc. incinerator for the destruction of polychlorinated biphenyls (PCBs).

To obtain detailed information about Rollins' special field services for PCBs, please contact the nearest Rollins' subsidiary.



3. Repackaging in strict accordance with all DOT lations.

efficient handling of hazardous wastes

When Rollins provides transportation, Rollins will take title to the waste following departure from the customer's plant. Rollins then assumes sole responsibility for any and all damages and holds its customer harmless from any and all damages and liabilities.*

* Except when a customer fails to comply with its warranty concerning the hazardous waste material.

The Rollins' fleet of specialized trucks are capable of handling a wide range of liquid, solid, and semi-solid hazardous wastes . . . and this service is supported by experienced drivers who are specially trained to handle hazardous wastes.

Before the decision is made to handle a customer's waste, a waste data sheet is completed by the customer and a sample is analyzed to determine an acceptable treatment/disposal method. After a waste-disposal contract is executed and waste is received for treatment, each load of waste is sampled, re-analyzed for conformity to specifications.

At every regional waste-treatment plant, Rollins maintains secure storage facilities with around-the-clock supervision.

solids, semi-solids, liquids and gases

High-temperature incineration is one of the processes employed by Rollins to dispose of waste products such as chlorinated and non-chlorinated hydrocarbons . . . polychlorinated biphenyls (PCBs) . . . pesticides . . . herbicides . . . off-spec pharmaceuticals . . . and a wide range of other organic compounds.

Liquids to be incinerated are analyzed and stored according to their burn and compatibility characteristics. Then, they are blended for uniformity, to prevent chlorine generation and for efficient burning and scrubbing characteristics . . . a synergistic approach for efficient treatment of hazardous wastes . . . efficient energy blending plus economies of scale.

Liquids and gases are incinerated in turbulent combustion furnaces at temperatures in excess of 2000°F per regulations.

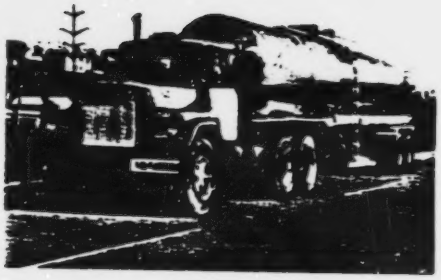
Incinerator Gases Are Scrubbed

Combustion gases from the liquid burner and the kiln pass through a high residence time afterburner to assure complete combustion. Hot gases from the afterburner are quenched and scrubbed in high-energy venturi or wet electrostatic scrubbers . . . effectively and efficiently removing coarse and submicron-size particulates and acid gases.

Gas absorption towers remove acid gas constituents which are alkali neutralized. Mist eliminators remove entrained droplets.

Scrubber blowdown is pH adjusted to neutral while discharging to final ponds. Exit stack-gas emissions, including steam, carbon dioxide, and excess air meet applicable regulatory limits.

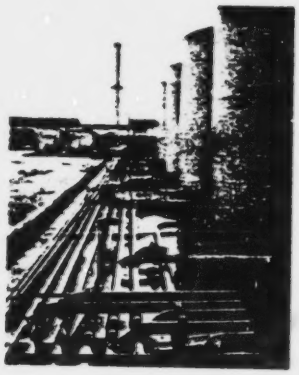
1. Rollins' collection/transportation services.

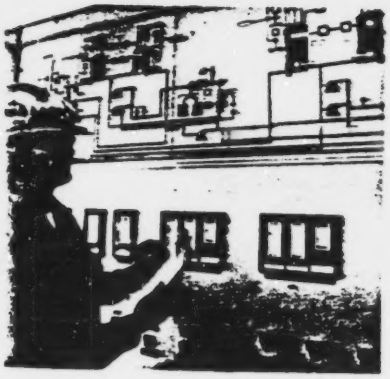


How Rollins handles industrial wastes...

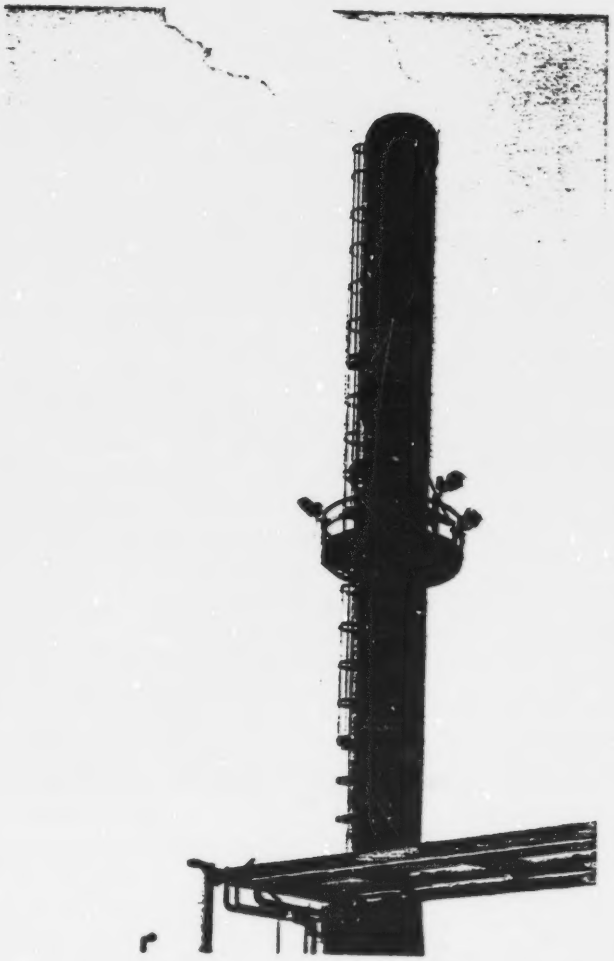
3. Rollins' storage facilities.

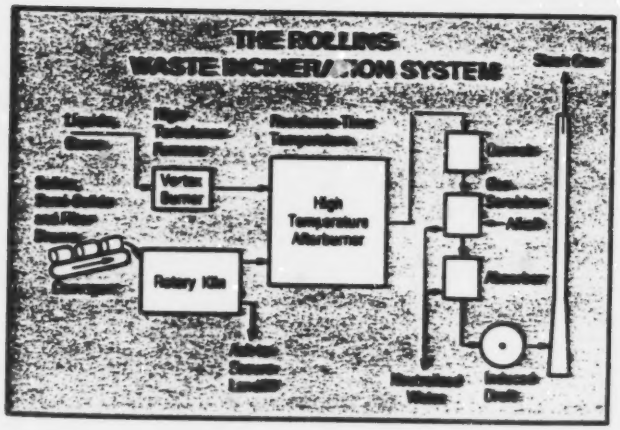
2. Evaluation: Rollins' laboratories are equipped with sophisticated analytical instrumentation.





Incineration at regulatory-approved temperatures with hot-zone residence time over two seconds, followed by advanced technology gas-purification systems, produces environmentally safe stack-exhaust gas at Rollins' subsidiary waste treatment/disposal facilities.





Wastes are *chemically treated* by Rollins to reduce toxicity and to form more stable chemical compounds. Other wastes are treated by specially designed *biological degradation* systems.

Physical, Chemical and Biological Liquid-Waste Treatment

Rollins has the capability of receiving and treating for disposal a wide variety of inorganic and organic liquid wastes. These wastes may range from oily waste waters containing free and/or emulsified oils and dissolved metals to acidic waste waters containing metals and organics.

Treatment processes generally involve skimming free oils for incineration, followed by alkali addition for neutralization, solids separation by sedimentation, and biological treatment of the aqueous organic phase. De-emulsifiers, oxidizers, flocculants and coagulants are used as required.

Biological treatment is used to treat wastes such as aqueous solutions of acetic acid, phenols and other degradable organic compounds.

After equalization, pH and nutrient adjustment, the waste stream is fed into an activated sludge recycle aeration basin where biological degradation of the organic chemicals takes place. By careful control of operating conditions, nutrient and waste feed concentrations, an extremely effective bacterial strain may be cultivated for the bio-degradation process.

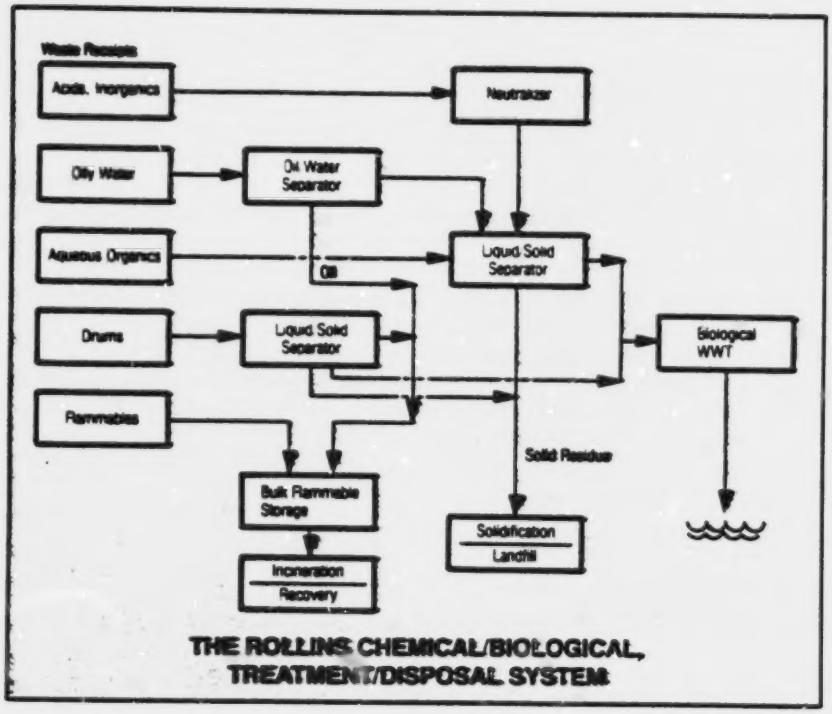
The discharge stream from the aeration basin is passed through a clarifier where underflow sludge is partly recycled to maintain aerator biomass. The balance of the sludge is wasted to disposal. The clear liquor overflow is discharged to the facility's final stabilization ponds.

Rollins operates secure, specially engineered landfills with leachate collection and ground-water monitoring systems . . . for disposal of drummed and bulk solids and pretreated sludges.

All Rollins' secure landfills represent the best available technology in design, engineering and monitoring for final disposal of industrial hazardous wastes.

All sites are operated under strict compliance with health, safety and environmental standards and with appropriate permits from federal and state authorities.

1. Preparation of landfill cells . . .



THE ROLLINS CHEMICAL/BIOLOGICAL, TREATMENT/DISPOSAL SYSTEM

1. Totally integrated storage facilities at each Rollins' location.

2. Final byproduct of Rollins' chemical and biological treatment disciplines is a waste water, discharged in strict compliance with the National Pollution Discharge Elimination System (NPDES).

2. . . . and fixation basins.

3. Depositing wastes in controlled fixation basins.

4. Totally secure chemical landfill.

Controlled injection of aqueous wastes... at a truck and barge accessible site.

Some industrial wastes — which do not require extensive pretreatment — may be disposed of safely and efficiently by controlled deep well injection, another service from Rollins, the only full-service company that offers, on a permitted basis, all the major *environmentally sound*, waste disposal technologies.

At its own barge and truck accessible site near Baton Rouge, Rollins operates a secure, deep well injection facility. This facility will accept many aqueous saline wastes, including wastes which are cross-contaminated with more than one chemical. Large-volume waste streams can be disposed of at relatively low cost.

Underground injection is a very practical, cost/effective solution to some difficult disposal problems. Acceptable wastes, however, must be injected only into porous zones of relatively low pressures which are sealed — above and below — by impermeable strata.

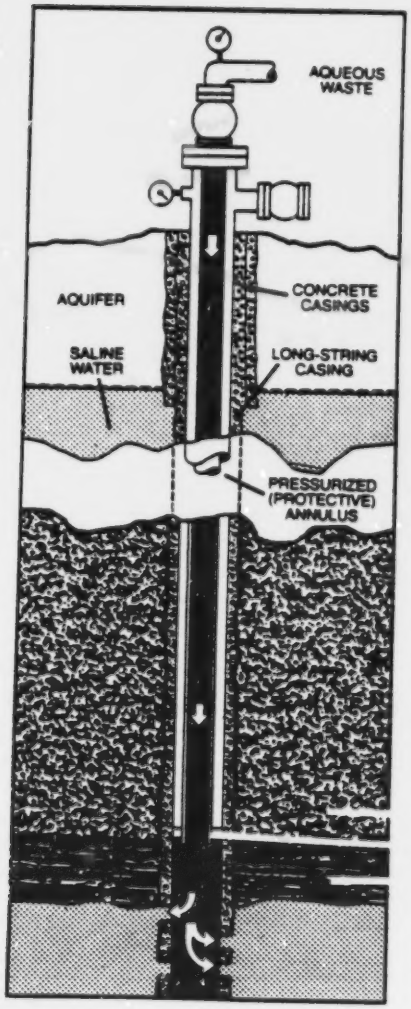
Perfect Geological Location

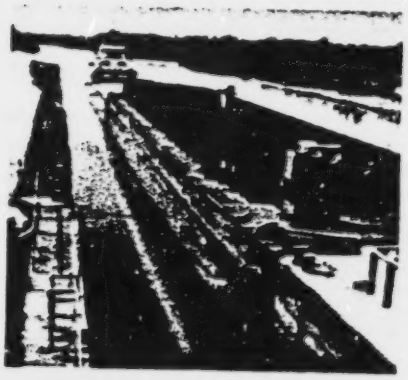
Rollins' controlled deep well injection facility at Bayou Sorrel, La. is located on the Intercoastal Waterway, at a site where geological conditions are ideal for underground injection of waste caustics, industrial cleaning solutions and many other alkaline wastes — from refineries, chemical and petrochemical complexes, ship and barge cleaning operations, and industrial plants.

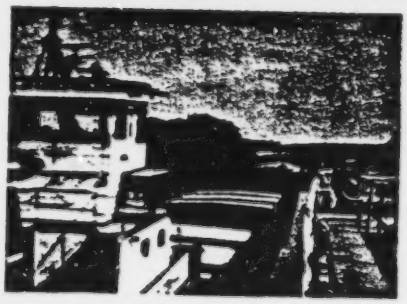
This secure, permitted facility includes ■ an on-site laboratory to verify waste specifications ■ continuous monitoring of operations to control injection pressures ■ equipment to detect any possible leaks of injected waste fluids within or around the well ■ and a commitment from Rollins to maintain the deep well disposal facility in accordance with strict state and federal pollution-control regulations.

Secure, Isolated, Permeable Zones

The permeable receiving zones are adequate to contain large volumes of injection — without increasing hydraulic pressure enough to fracture the sealing layers of rock.







Integrated, Hazardous Waste Management Facilities

Rollins pioneered the concept of regional waste management facilities. And Rollins is the only service company that offers all of the major waste treatment technologies — on a commercially feasible scale.

- Unsurpassed Experience
- Breadth of Technology
- Comprehensive Programs
- Transportation Expertise
- Custom-Designed Field Services
- Contract Protection
- Computerized Records
- Energy-Efficient Operations
- And a Corporate Commitment to operate every regional facility and to provide every field service with the best available technology and in accordance with approved health, safety and environmental standards.

about
Rollins' waste management services, call your nearest facility:

Rollins Environmental Services, Inc.
One Rollins Plaza, Wilmington, DE 19899 • (302) 429-2768

Rollins Environmental Services (NJ) Inc.
P.O. Box 221, Bridgeport, NJ 08014 • (609) 467-3105

Rollins Environmental Services (LA) Inc.
P.O. Box 73877, Baton Rouge, LA 70807 • (504) 778-1234

Rollins Environmental Services of Louisiana, Inc.
Route 2, Box 380, Plaquemine, LA 70764 • (504) 659-2446

Rollins Environmental Services (TX) Inc.
P.O. Box 609, Deer Park, TX 77536 • (713) 479-6001

Rollins and its subsidiaries are collectively and individually referred to herein as "Rollins".

Rollins
Environmental Services, Inc.
One Rollins Plaza, Wilmington, DE 19899
(302) 429-2768

C A N A D A

The Need for a Facility in Ontario

By: Dr. Rodger Schwass
Association of Municipalities
of Ontario, June 1982

THE NEED FOR A FACILITY IN ONTARIO

A tremendous amount has been accomplished in the past two decades to deal with waste problems. Local air pollution has been substantially reduced around industrial areas, despite great industrial growth. Ontario Hydro has converted many of its plants from coal to gas or nuclear power. The mercury-cell plants which caused the mercury problem have been largely replaced by cleaner and more modern units. Hundreds of towns and villages have upgraded their water and sewerage systems with help from the Ministry of the Environment, and most rivers are being cleaned up.

A great deal has been accomplished with industrial wastes as well. In 1960, many Ontario industries simply dumped industrial wastes into the nearest municipal land-fill site or allowed them to drain into a nearby river. I remember one case in which chemical wastes killed a number of prize Holstein cows near Elmira and caused a major incident. Since 1960, most manufacturers of toxic wastes have come to recognize the hazardous nature of their wastes and have invested heavily in recycling, in-plant incineration or storage and other techniques designed to minimize output. The sharp increase in the cost of all chemicals has made it more economical to recover solvents, pigments and dyes and catalytic agents. In some cases, new processes have been introduced which have eliminated nearly all the wastes which were generated by earlier techniques.

A year ago, Pollution Probe examined five good examples of clean and profitable recycling. One was the Toronto Star, which invested $28,000 in 1978 in an ink recycling unit. It paid for itself in six months and eliminated another $15,000 in disposal costs at a landfill site.

Minnesota Mining and Manufacturing introduced silver recycling and recovered $650,000 in 1980, in their photofinishing operations. They now recycle their developer, bleach and fixer baths. Other examples are equally encouraging and more Ontario manufacturers are looking hard at recycling opportunities.

By now you must be asking yourself: "If things are going so well in the industrial waste management business, then why are we here?"

We are here because there are 28,000 manufacturers in Ontario with more than five employees. Many of them cannot afford to develop a proper disposal facility for their wastes. One option is to build many small disposal sites around the Province, but the tremendous variety of wastes makes it very difficult to deal with the problem of disposal in small plants. At the moment, much of this waste is disposed of in small municipal landfill sites or in convenient places on back roads. At least some of this material is very dangerous and we are fortunate that it has not caused more trouble than it has.

In 1978, a number of members of my Faculty and several students searched for the disposal sites in Ontario where industrial wastes had been dumped. They found nearly 1000 of them and we are quite confident that there are at least another 1000 and perhaps more.

The Ministry of the Environment reviewed the situation at each of the sites and concluded that only about twenty-five were at all suitable for the storage of industrial wastes. In the three years since then, the number has been reduced to seven. No one can be sure that the remaining sites are entirely satisfactory. No one can be sure that they will remain open indefinitely. We do know that a system must be designed and built which is entirely satisfactory and it must be completed as soon as possible. The issues at stake are human safety on the one hand and the strength and growth of the Ontario economy on the other. Without proper sewerage systems, your town or city could not be made safe for people nor could it be a suitable place for new industry and more jobs. Your Province must deal with industrial waste as responsibly as you have dealt with your sanitary waste at the municipal level.

The fact is that, despite the recycling and in-plant disposal that is going on, Ontario industry produces at least 80 million gallons of toxic industrial wastes each year, based on waybill information. We know, however, that waybill information is not complete. It attempts to

record only wastes which are transported on public highways from the point of generation to a disposal site. We do not know how much waste is being stored, recycled, incinerated or disposed of on the generator's premises, in lagoons and landfill sites. It has recently been estimated that over 70% of industrial wastes in Ontario go untreated and uncontrolled into landfills and dumps, which are not engineered to store such material. There may be a serious risk of these chemicals becoming concentrated in the food chain, where they can interfere with cell structure and reproduction. The final effect may be mutations, cancer and reproductive failure in animals and humans.

If we fail to deal properly with industrial wastes, the other problem will be economic. We know that a direct relationship exists between the amount of production in an economy and the amount of waste generated. If Ontario is to grow in the next twenty years to a forecast 10.3 million people, and if we are to generate the jobs they will require, a plan and system for dealing with toxic industrial wastes is absolutely essential. No businessman will invest his funds in a Province where the situation is not under control and where facilities are not available to deal with his wastes. He knows he cannot recycle everything. He knows that facilities will exist in New York, Pennsylvania, Ohio, Michigan and Alberta.

To develop the plan and the system, the Ontario Waste Management Corporation has been created. Its mandate includes working closely with industry to encourage and support the introduction of recycling and in-plant techniques for waste disposal, and then to create the facilities needed to take care of the more intractable sludges and chemicals which remain.

The process of developing a suitable system is not much different from the process you followed when you developed your sewerage systems. Studies are undertaken to determine how to do the job. A plan is drawn up, including all of the reasonable alternatives. Hearings are held to discuss the alternatives and the most suitable plan is chosen and implemented.

A number of important studies have been completed by the OWMC. One of these includes a waste reduction study, to determine the existing and possible opportunities for reducing wastes. Pollution Probe, with financial support from the Corporation, completed the study "Profits From Pollution". This study identified successful waste reduction practices, and will be made available to individual plant owners in Ontario.

Where wastes are reclaimed which are useful to other buyers, the Canadian Waste Exchange will be used. This program was set up in 1978 after a detailed study by the Ontario Research Council. It provides information to 4000 companies across Canada about the availability of recycled materials. Customers have been found not only in Canada, but in the U.S., in Japan, India and the Philippines. About 185,000 tonnes of wastes, valued at $4.8 million, are traded each year.

When that is done, when all that can be recycled has been recycled, and all that can be traded is traded, and all that can be used for boiler fuel in the plant has been used, there will still be industrial wastes. Some of it will be evil, bottom of the barrel stuff, including PCBs, glycols, pesticides and phenols. Some of it will be extremely toxic. These wastes are what is left of chemicals and processes which are absolutely essential to our industrial system if we still want to engage in the following industries and if we want to use the products they produce.

metal mining	machinery manufacture
oil and gas extraction	electrical and electronics
quarrying	transportation equipment
textiles	measuring, analyzing and controlling equipment
paper	agriculture
chemicals	business services
rubber and plastics	health services
leather goods	primary metal industries

If that sounds like a profile of Ontario industry, it is. But that is the list of primary sources of significant quantities of hazardous wastes taken from a study conducted in Alberta. It should deal with the question whether we are unique in having the problem.

Can facilities be designed to deal with industrial wastes? Nearly all advanced countries have processes to deal with various kinds of industrial wastes. Over 100 designs are now being reviewed by consultants to OWMC to determine which are most suitable, adapted and improved for Ontario conditions. There are physical processes to filter out suspended solids, to evaporate water from liquid wastes, to separate thick and thin liquids through membranes, and to centrifuge solids out of liquids. They include chemical processes to blend acids and caustics together to neutralize them, to reduce chemicals through oxidation to a storable form, to precipitate out solids, to exchange ions and to solidify the final product. For chemicals such as PCBs and DDT, incineration may be the only solution. It is accomplished at very high temperatures to minimize the effect on air quality outside the plant. Finally, for some wastes, tame bacteria are used to eat the waste. The bacteria break down the chemicals into forms of matter which can be safely stored in the landfill site.

By the end of these processes, an inert product is produced which can be safely stored. In an extreme case, the waste can be sealed in glass or turned into an aggregate form which is not toxic. Experience in Germany, France, Britain and the U.S. show that we can build safe and reliable facilities for industrial wastes and eliminate all fear of future contamination of air or water.

The most difficult question is where to put the facilities.

From an economic point of view, the facilities should be near the source of waste, to minimize transportation costs. The plant or plants should be near large industrial centres so they can operate at full capacity on a year-round basis. All facilities need to be close to road and rail routes.

From a geological point of view, the permanent disposal facilities should be located on deep impervious clay soils, where natural conditions provide a backup safety system to those designed into the plants. Incinerators and processing facilities do not require these stringent natural qualities.

From a meteorological point of view, the facilities should be in areas where winter road conditions do not create insurmountable hazards in transporting wastes to the plants. They should not be upwind of major towns or cities, although air emissions will be minimal and controllable.

There has been an argument that the plant should not use class one or two agricultural soils. It should be pointed out that the individual secure landfill facilities will probably require no more than 100 acres each. If an equally good site can be found on lower class agricultural land, it should be favoured.

From a political point of view, the facilities must be selected to be reliable, safe and virtually mistake-proof. There must be a full and open process of selection of the type, nature and location of facilities. People must be convinced that the plants are the best available technology, located on the optimum sites, designed with esthetics and traffic flows in mind. It must be the safest and best set of waste disposal facilities in the world, as the final step in a system which is the finest we can design.

A system must be built. The OWMC has rejected the South Cayuga site because there were serious doubts about its suitability. It has pledged to follow a process which is open and which considers the location of suitable plants from every point of view. It will begin with an inventory of basic hydrogeological regions of Southern Ontario for facilities. Once the groundwater and soil conditions are better understood, environmental and engineering studies will be examined in minute detail. Public hearings will be called at which concerned citizens and organized groups will be assisted to express their views.

Many people do not feel that they should be expected to welcome a facility such as the ones which must be built, for they have not contributed to the creation of industrial wastes. There is no doubt that it makes social and economic sense to locate the facilities as close to the generators of waste as possible. If the major benefits are to the cities, the wastes should be dealt with there, according to this argument. However, we must be fair, as citizens of this Province, and recognize that, if we drive a car, use electricity or plastics, read a newspaper or own a piece of machinery, the production and use of these goods contributes to the production of toxic industrial wastes. On my farm, the chemicals, pesticides, animal feed, machinery and equipment all caused their share of toxic wastes to be generated. Processing the output of the farm causes some more. We are all involved.

That is why we are here today. All of us have public as well as private roles to play, and we have a responsibility to ensure that this society continues to grow, that it retains its political and economic stability, its justice and its freedom.

To accomplish all this at once, many elments must be successfully addressed.

- The technology must minimize the need for final waste disposal. Processing, recycling and recovery must be emphasized before final waste processing is undertaken.

- The public must be made aware of the consequences involved both in accepting and rejecting a site.

- Siting factors must be clearly established.

- The public must have confidence in the criteria for selecting the final sites.

- The public must be involved throughout the planning and facilities development process.

- If there are local costs, they must be covered by a stream of benefits which will flow to all citizens of the Province when we can offer industry a safe and efficient system for waste disposal.

We would hope and expect that the benefits of having the facilities would far exceed the costs to the municipalities where plants are located, just as provincial benefits will exceed provincial costs.

If we can accomplish this in the next two years, we will have upheld the criteria of justice and freedom in the process and will have strengthened the essential partnership between the municipalities, the Government of Ontario and the Government of Canada.

POLLUTION PROBE

Profit From Pollution Prevention - 1982
Pages 3 - 8

A Sound Waste Management Programme: Ounce of Prevention Worth Pound of Cure

Any company can benefit both the environment and its financial picture by implementing a sound waste management programme. Economic rewards to be gained from pollution avoidance take hard work, commitment and an understanding that monetary returns may entail some risk. Pollution prevention should not be segregated from other affairs in the company but be integrated smoothly into every phase of the production process. Doing so will enhance productivity, not detract from it.

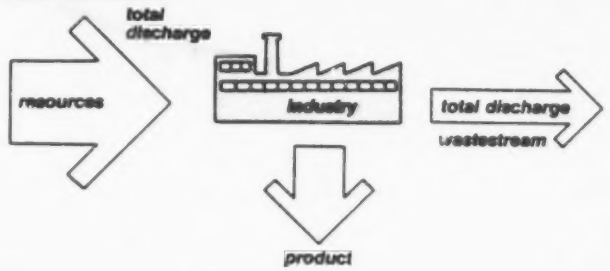
The availability of cheap landfill sites has acted as a disincentive to the capital expenditure needed to implement waste recovery systems. Now that environmental concerns are closing these hazardous dumps, shrewd businessmen are looking to investing in waste avoidance.

It is important to distinguish between conventional pollution abatement and waste recovery technologies. Conventional pollution abatement such as end-of-pipe treatment technologies generally require the addition of substantial amounts of chemicals and energy to remove the hazardous components from a wastestream (see Figure 1). Typically the resultant sludges are then transported to a landfill site for burial. Instead of eliminating wastes, a water pollution problem is transformed into a potential land pollution problem. The treated wastewater is discharged to a sewer or body of water for further purification or dilution. Conventional pollution abatement is characterized by open-ended systems that use resources once and discard the waste products.

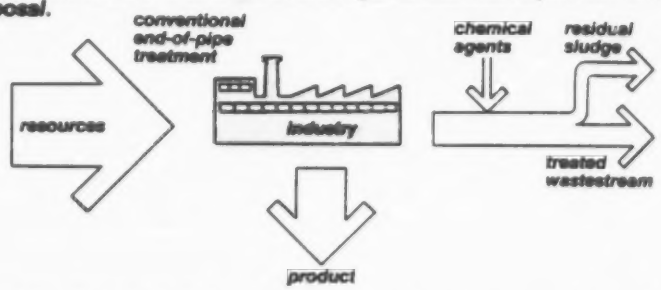
In contrast, waste recovery attempts to achieve closed-loop sys-

Figure 1
Varying Approaches to Waste Management

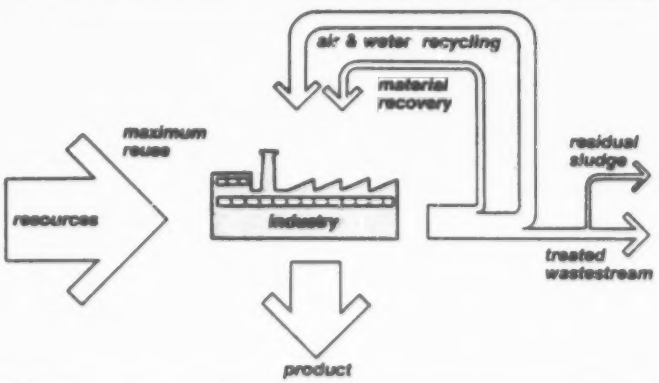
It is uncommon for industry to discharge its total effluent stream without some pretreatment.



In conventional end-of-pipe waste treatment, large amounts of sludge, slurries and other residual material are generated that require additional disposal.



Industries that maximize material and water re-use generate relatively small volumes of wastewater and residuals requiring disposal elsewhere.



tems in which process wastes are recovered and re-used repeatedly on the premises. Clearly not all wastestreams lend themselves to recycling, particularly if the wastestream contains byproducts of no use to the processor generating the waste. In such instances, a firm may transfer the wastestream for re-use by another industry or alter the production process to minimize the generation of non-reclaimable wastes. Waste recovery is superior to conventional pollution abatement because industry can conserve resources and minimize the volume of waste requiring ultimate disposal.

Land disposal of hazardous wastes is recognized by many as the waste handling method of last resort.[6] In its place, the following hierarchy is gaining greater prominence as the optimal management strategy for hazardous wastes:[7]

1. Reduction
2. Recovery
3. Treatment
4. Disposal

The goal of a waste management system is to utilize the most cost-effective combination of management options to handle wastestreams within the confines of applicable regulations.[8] A scenario involving recovery, treatment and disposal is suggested for handling waste solvents. The solvent is distilled to recover a re-usable fraction. The distillation process leaves a tar-like still bottom which may be incinerated for heat recovery, but which yields an ash requiring further disposal.

Large-scale capital expenditures are by no means the only way to avert pollution. Low-cost measures such as good housekeeping practices, routine checks for faulty and leaking processes, regularly balancing inputs and outputs to identify unusual losses, and making minor process changes all help to minimize pollution in a cost-effective manner. Industry could rapidly eliminate a significant percentage of its current hazardous wastestream through such simple and profitable measures.

1. Waste Reduction

The ideal solution is to reduce waste at source by changing industrial processes so that waste generation is minimized. Several practices are described that help achieve this goal.

Waste Audit

A first step in any firm's waste reduction programme should be a waste audit. The audit may be performed by a consultant, or by existing staff in response to questions such as:

How much waste is produced?
Which are the hazardous components?
What is the processing efficiency?
What are the costs of disposal associated with each major wastestream?
Are there any leaks or unaccounted material losses?

A waste audit is used to review a company's waste management programme and operating practices. Based on an audit, a company can evaluate options for handling wastes such as comparing the economics of on-site versus off-site waste handling. Audits can identify potential opportunities to reduce waste generation through process changes, product substitutions or recycling measures.[9]

One component of a waste audit is completion of a mass balance (also referred to as a materials balance) which compares resource inputs with product and waste outputs. Small and medium-sized businesses frequently lack detailed information of this type.

Completion of a waste audit may yield surprising information on the quantity of wastes discharged. Such information not only identifies problem areas but can spur company management into fighting the war on waste with new vigour. Once waste areas have been identified, waste reduction goals should be established that can be measured and that are attainable.

Product Reformulation

Although a primary manufacturing company may have the scientific resources and capital to control pollution through closed-loop processing, the sale and transfer of potentially hazardous chemicals to a smaller industry down the line may present environmental problems beyond the control of the small end-user. The secondary manufacturer who inherits product-related pollution problems from a primary manufacturer may have to build costly control facilities to cope with the problem, or find a substitute product. If the secondary manufacturer purchases a substitute product, the primary manufacturer will have lost a market for his product.

Some manufacturers are responding to the plight of the end-user by reformulating their products to minimize pollution problems down the road. An example of this is seen among chemical companies that manufacture polyester resins for use by plastics processors that produce contact moulded items such as bathtubs and boat hulls. During the moulding process, toxic styrene monomer is released into the air. Some chemical producers now manufacture a line of styrene-suppressed resins that reduce styrene loss into the air by 70% compared with nonsupressed systems.[10] Although contact moulding with polyester resins makes up only a tiny segment of the plastics processing industry, it nevertheless provides a useful example of product reformulation by one manufacturer in response to contraints by an industrial end-user.

Substitution

When regulations are enacted that restrict the level of toxic pollutants in the workplace or the environment, industry usually has two recourses. A company can adjust its operation to mitigate pollution through reduction, recovery and treatment, or the company can refrain from using the polluting product at all. Instead,

the firm may seek to substitute a low-hazard product for the toxic one.

The replacement of solvent-based products such as paints, inks and adhesives with water-based products is a good example of product substitution. In many instances, the water-borne product is cheaper than solvent-based goods, while meeting or exceeding the specifications set by the users for its particular use.[11]

Solvents vary in their toxicity and environmental effects, however, most solvents share the common characteristic of being highly volatile. Larger companies may choose to meet their fugitive emissions problems by installing vapour recovery systems but for the small industrial user, substitution of water-based products may shape up to be the most cost-effective alternative.

More Efficient Equipment

For the smaller company, a five-digit price tag on waste recycling or treatment equipment may seem prohibitive. Instead, the firm may opt for plant modernization by installing more efficient processing equipment. In response to spiralling energy and feedstock costs, and increasingly stringent pollution regulations, equipment manufacturers have revamped their tools to process better, more quickly, with less pollution and using less energy. In some instances, it may be more affordable for a company to install efficient processing equipment than to retrofit existing equipment for pollution control.

Take the example of the dry cleaning industry. Much of the equipment currently in use was manufactured years before solvent loss and energy conservation were issues. The old models may be responsible for significant leakage of solvents into the workplace and the environment. Nowadays, equipment manufacturers are "building a tighter ship" to minimize solvent loss from the system.

To meet health and environmental regulations, a dry cleaning establishment may retrofit the existing situation by installing ventilation and vapour recovery systems.[12] However, in many instances the more cost-effective solution would be to invest in highly efficient dry cleaning equipment that would eliminate the need for elaborate ventilation systems.

Process Redesign

Industrial processes were designed in an era when productivity and quality were uppermost on the minds of company management. The importance of environmental protection in the last decade has sent process engineers back to the drawing board.

The new attention on resource conservation and minimizing pollution has yielded a wide range of process improvements in every industrial sector. Each plant is its own unique environment and as such requires the commitment of the plant manager to specify the process changes necessary to accomplish waste reduction.

One major process change applicable to many industries involves wastewater recycling. In some situations, wastewater from one operation may be clean enough for re-use as a water input in another part of the plant. Sophisticated separation equipment is now available for many wastestreams which can remove specific constituents for recovery or disposal, thereby leaving wastewater clean enough to be re-used.[13] Given the rising costs of end-of-pipe treatment for discharge to a stream or of pre-treatment for discharge to sewers, it may ultimately be cheaper to re-use wastewater rather than simply treat it for discharge.

Process Control

Although a small business may think twice about investing in a capital-intensive recovery system, a business of any size can implement low-cost improvements through process control and come out ahead. When systems in a plant are provided with regulating procedures in processing, the result is process control. Process controls may involve people or may be automatic. In the case of computer-assisted process control, the capital investment may be high although the resulting economic benefits may pay off the capital investment in a relatively short period of time.

Process control measures vary considerably from industry to industry. Process control ensures that unnecessary waste is minimized by ensuring that things are done right the first time. In the printing industry, for example, process control measures can slash paper wastage dramatically by ensuring that the inks, plates and presses are operating at optimum efficiency.[14] A poor printing job may mean that thousands of copies of printed material have to be discarded.

In the photoprocessing industry, implementing process controls means that chemical baths can be replenished in a manner that optimizes print quality and the life of the chemical bath.[15] This not only minimizes print and chemical waste, but also saves money.

Waste Concentration

Some hazardous wastes are so dilute that the cost of transporting them makes inter-industry exchange unfeasible. Oily-water wastes, for example, may contain 70 to 99% water.[16] Although the recovery of oil from the oil-water mixture may be a highly lucrative endeavour, trucking the water component over large distances is not. Commercially available equipment such as ultrafiltration units are available to concentrate the oil fraction from the wastewater.

Waste acids are another wastestream that frequently is very dilute. Some of the larger chemical companies have installed equipment capable of concentrating waste acids to a 95% concentration.[17] Concentrating wastewaters not only makes transportation more affordable but usually enhances the value of the wastestream.

2.
Waste Recovery

Recycling

Companies that generate wastes which are contaminated versions of process in-puts usually can benefit from in-line recycling. In-line recycling refers to the recovery and re-use of process waste back into the same process that generated it. Recycling efficiency is optimum if the recovery equipment is placed at the end of a specific processing sequence, rather than at the combined effluent outflow from the entire plant.

Ion exchange systems used in the electroplating field are a good example of in-line recycling. Although an electroplater may generate a variety of metal-laden wastewaters, metal recycling units placed in-line at the rinse tanks following each metal bath provide optimum and profitable recovery.[18]

Recycling wastes directly for re-use in the same process that generated it offers distinct advantages over the recovery of wastes for use elsewhere. A company should explore the possibility of in-line recycling before making arrangements to transfer wastes to another industry.

By recycling wastes directly on the premises, a firm is able to significantly reduce the purchase of new materials. Newspaper establishments that recycle dirty ink on-site end up with high quality ink and significantly reduced ink charges.[19]

There is another advantage to direct recycling. Take the example of the paint industry. It makes the most economic sense to reclaim the waste paint for its original purpose because industrial paint is custom-formulated for a specific purpose to meet very particular product and performance standards. Recovery economics favour the reclamation of enamel overspray as enamel and primer overspray as primer rather than the recovery of mixed paint sludges as a low-grade primer.[20]

The same holds true for oil and solvent recycling. Oils and solvents tend to be custom blended to meet user specifications. From an energy, materials and cost efficiency point of view, it is usually preferable to remove contaminants from the dirty waste and re-use it in the same process that generated the waste than it does to purify wastes to virgin purity for sale elsewhere. Virgin-purity recycled products may require additional blending and additives to meet customer specifications, a step that is minimized by removing few of these additives in the first place.[21]

Undoubtedly, not all wastes can be recycled directly back into the process. In such instances, the next option to explore is recovery and sale to another industry or professional waste reclaimer.

Waste Recovery

Businesses that generate a waste that is not directly re-usable on-site may benefit by recovering the waste for other uses. The photoprocessing industry, for example, produces a silver-rich wastestream from which the silver can be recovered on the premises and sent to a refiner for purification.[22] The purified silver is sold and re-used by businesses other than photofinishers.

Similarly, plastic wastes may be recovered for other than original uses. Certain plastic wastes that have lived a useful life are recovered and re-used to make construction materials.[23]

Processing of dairy products yields wastestreams rich in starch and nutrients that can be recovered for use in a variety of products including baked goods and animal feeds.[24]

Waste Segregation

Waste segregation is an important concept that is coming into greater use. In the past, when using conventional end-of-pipe waste treatment methods, there was little advantage to be gained from segregating wastestreams. With the new interest in recycling and recovery, keeping wastestreams separate takes on new importance.

A company has the best chance to recover materials if it does not mix in other wastestreams which will contaminate the stream from which it is trying to recover specific substances. The same holds true for energy recovery. A company has the best chance to recover heat if it integrates a hot water wastestream back into the process, rather than mixing it with a cold wastestream.[25]

It pays to segregate toxic wastestreams from other process wastes. Usually, only a small number of wastestreams contains toxic substances. Toxic wastes may require special handling which is usually made easier and cheaper if the wastestream is small. There is no advantage to contaminating relatively innocuous wastestreams with toxic ones.

Another reason for segregating wastestreams is that some wastes may be directly usable by another industry. For example, solvent wastestreams from the electronics industry, which contain only tiny amounts of metals, may be so clean as to be directly usable for wash-up in the paint industry.

Inter-Industry Exchange

For those situations in which on-site resource recovery is not feasible, one company may transfer its wastes to another for re-use. The transfer of wastes from one company to another means that both companies benefit economically from the exchange.

In order for that transfer to occur, the two companies must know of each other's existence. This matching function may be accomplished by a waste exchange programme or through a broker. A waste exchange strives to match waste generators with waste users, thereby linking potential trading partners.

One company may produce a waste continuously for years. The receiving company may use the recycled waste as a raw resource in its manufacturing processes over the years. In such a system, a profitable symbiotic relationship

is established that can be expected to continue.

Combine Specific Wastestreams

Most chemical treatment processes used by industry today involve the addition of virgin chemicals including lime, metallic salt cations and sodium hydroxide. The use of virgin chemicals is both expensive and demanding of industry's supply of chemical resources.

Instead of relying solely on virgin chemicals, some industries have learned to precipitate or neutralize one wastestream with another. For example, waste acids from one company may be neutralised with waste alkalis from another company.[26] The blending of wastestreams must be based on a thorough knowledge of the contaminants present in each wastestream and an understanding of how these wastestreams will react. Failure to do so may result in the dangerous release of toxic gases.

3. Waste Treatment

Those wastestreams remaining after waste reduction and recovery options have been exhausted should undergo suitable treatment. Ideally, waste treatment will render the material completely innocuous. In other situations, waste treatment may only reduce the toxicity of the wastestream or reduce the volume of material requiring ultimate disposal. Unit waste treatment operations are discussed in the chapter Waste Treatment and Disposal Technologies.

4. Waste Disposal

Even those companies active in industrial waste reduction and recovery may generate a wastestream, albeit small in volume, that requires disposal. Having exhausted reduction, recycling and treatment options, a company may be left with a solid residue containing toxic components that will require disposal in a secure landfill site.

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Waste Recovery Technologies

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Resource recovery is the science of material separation — netting the process chemical from the wastewater, wresting the metal from the sludge, capturing the protein from the pomace, or separating the gold from the dross.

The key to the separation of substances is the understanding of their nature and their differences. Two compounds cannot be separated unless they differ in some chemical or physical manner. The knowledge of these properties is the domain of the chemist and the physicist. Their fields involve the analysis of how and why materials behave differently to external pressures. Scientists have developed extensive data on a wide variety of chemical and physical parameters. What they tell us about ionic charge, specific gravity, solubility, reactivity, size, shape and a host of other parameters form the basis of separation science.

Once the differences are known, the engineer can devise the equipment that utilizes that knowledge as the lever to pry materials apart. Because the chemists and physicists can supply him with a host of properties on which two substances will differ, the engineer's response can encompass an enormous range of technologies. Indeed, separation science is a field that has been called an inventor's paradise. Many commercially available

separation technologies exist at present, however the future should bring an even greater array of recovery innovations.

This chapter is meant to present a brief overview of some of the separation technologies for which in-plant performance is a proven success. Other technologies applicable to waste recovery include filtration, centrifugation, flotation, anaerobic digestion, pyrolysis and wet-air oxidation. Because these technologies are used primarily for waste treatment or destruction at present, they are described in the Waste Treatment and Disposal chapter.

It should be noted that several of the technologies such as precipitation, filtration, anaerobic digestion, wet-air oxidation and pyrolysis described in the Waste Treatment and Disposal chapter are also suitable for resource recovery. Their description appears in the treatment and disposal chapter because these unit technologies are most frequently used in conjunction with destruct or landfill methods.

1. Carbon Adsorption

Carbon adsorption technology has a long history, including the commercial use of activated carbon in the sugar industry for decolorization and as a filter in war-time gas masks in the early 1900s.[1] It was not until the 1970s that carbon adsorption technology gained prominence in the treatment of liquid industrial waste. At present, carbon adsorption technology is used predominantly to remove contaminants from a wastestream for further disposal through incineration or landfill. As recovery economics improve, greater attention is placed on the implementation of carbon adsorption technology for the removal, recovery and re-use of select wastestreams.

Waste Recovery Applications

The affinity of activated carbon for organics makes it a useful tool in removing organic contaminants in wastewaters, particularly industrial contaminants such as select solvents and chlorinated pesticides that are resistant to biological degradation and may be toxic to a biological treatment process. Carbon adsorption is also successful at removing gas-phase organics such as solvents from solvent-laden air.

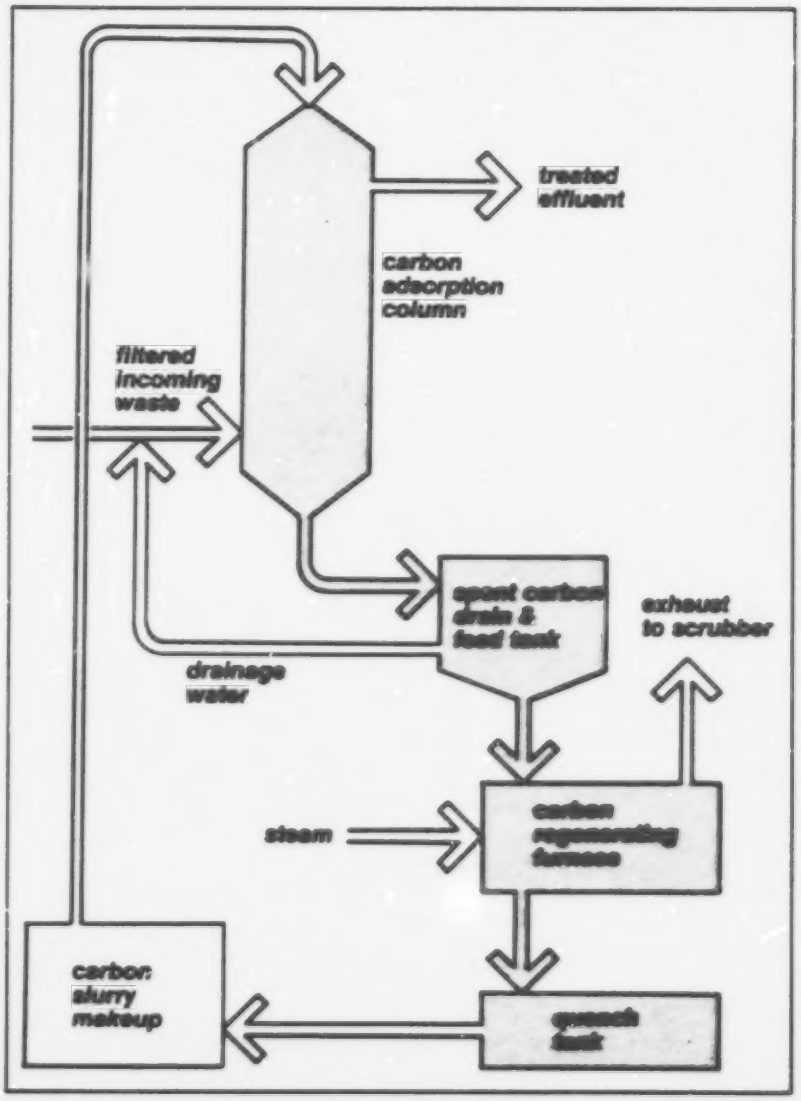
Industries which treat segregated industrial wastestreams with activated carbon include the textile, pharmaceutical, dyestuff, resin, detergent, chemical, pes-

Figure 1

Carbon Adsorption System With Thermal Reactivation Cycle

Thermal reactivation destroys the adsorbed organic solutes in a furnace at temperatures around 900°C and with the introduction of steam. Carbon lost from the system is made up with fresh carbon. The use of afterburners ensures that organic compounds are destroyed. Scrubbers are used to remove particulates from the furnace exhaust.

Source: "Industrial Wastewater Treatment by Granular Activated Carbon," *Industrial Water Engineering*, January/February 1974.



ticide and oil refining industries. Organic contaminants removed through carbon adsorption include dyes, phenols, polyethers, TNT, cresol, toluene, xylene, xylol, resorcinol, chlorophenols, chlorobenzenes and insecticides.

In general, carbon adsorption is suitable for the removal of organic contaminants with a high molecular weight, low water solubility and low polarity, however, exceptions do occur. Industrial wastestreams vary in the types of impurities that they contain. Some contaminants are easily removed using carbon adsorption, whereas other organic impurities show a poor affinity for the carbon. Long-chain organic soaps and other macromolecules such as certain dyes may be too large to reach a significant fraction of the carbon's internal pores, making removal inefficient.[2]

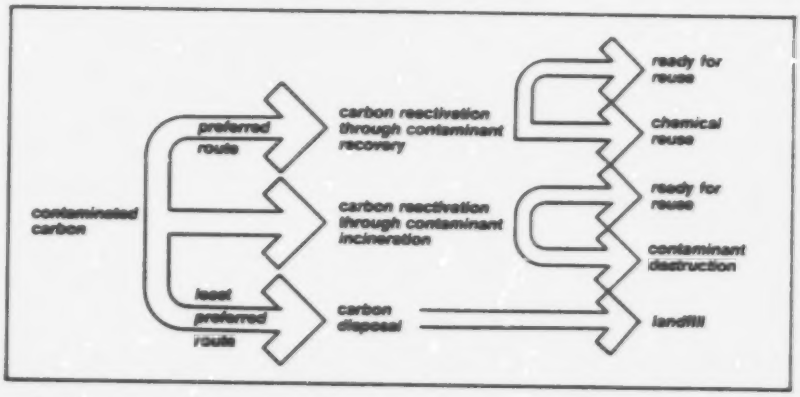
Activated carbon adsorption has been demonstrated to be feasible for the removal of low concentrations of certain inorganic compounds from aqueous industrial wastestreams. The following is a partial list of inorganic chemicals that can be removed by activated carbon: alkali metals from basic solutions, ammonia, arsenates, calcium hypochlorite, chlorine, chromium, cobalt, copper, cyanide, dichromates, ferric salts, gold chloride, hydrogen sulfide, hypochlorous acid, iodine, lead, mercuric chloride, molybdates, permanganates, selenium, sodium hypochlorite and zinc.[3,4]

Process Description

Carbon adsorption is a separation process which relies on the weak physical attractions between contaminant molecules and the charged surface of carbon. Typically, activated carbon is used because of its porous nature and high adsorption capacity. Adsorption is a suface phenomenon and is reversible. Heat, steam or solvent may be applied to remove the adsorbed contaminants from the surface of the carbon, thereby regenerating carbon for future re-use.

In decontaminating aqueous wastestreams, wastewater is passed through a tank or column filled with activated carbon (see Figure 1). The contaminants are trapped in the pores of the carbon by surface attraction forces and purified water passes through the unit. As more and more contaminants adhere to the pore surfaces of the carbon, the adsorptive capacity of the carbon is exhausted.[5]

Figure 2
Carbon Reactivation Options



Three options exist for restoring capacity to the treatment system (see Figure 2). The preferred route from a materials and energy conservation aspect is to strip the carbon bed of its contaminants in a manner that permits recovery and re-use of these contaminants. This practice may be feasible if wastestreams are kept segregated and if relatively large quantities of select contaminants occur. Carbon adsorption systems have been used to recover solvent vapours generated during adhesives manufacture, textile finishing, printing, coatings application and dry cleaning.

Installations exist that chemically recover adsorbed phenol, acetic acid, p-nitrophenol, p-chlorobenzene, p-cresol and ethylene diamine from carbon used to decontaminate segregated wastewater effluents.

For wastestreams that contain a large variety of small amounts of contaminants, chemical recovery might not be feasible, however, the reactivation and re-use of the carbon bed may still be possible. In the second option, the contaminated carbon is incinerated in a furnace at around 900°C to destroy the organic contaminants, thereby re-opening the pore spaces in the carbon material. Although the cost of on-site carbon regeneration processes may be prohibitive to the small operator, the smaller company should investigate the possibility of carbon regeneration elsewhere at an established facility.

The third option used in handling contaminated carbon is to bury it in a landfill site.

Environmental Aspects

The greatest environmental concern is associated with the landfilling of non-regenerated carbon impregnated with potentially hazardous material.

When the carbon is regenerated chemically by washing with solvents, acids or bases, potential impacts are associated with the handling of particular regenerants. The use of solvent regenerating agents requires proper controls to minimize fugitive solvent emissions.

Thermal regeneration of the exhausted carbon bed may yield air pollution during incineration, however, air pollution can be minimized through the use of control devices such as scrubbers and baghouses.

2. Distillation

Distillation has been in widespread industrial use for many years in the petrochemical industry to purify chemicals or separate them from secondary byproducts. In recent years, distillation principles are applied with greater frequency to treat liquid organic wastestreams.

Waste Recovery Applications

Distillation is applicable to the separation of water-organic or organic-organic liquid mixtures where the boiling points of those liquids differ. In the case of simple purification of a contaminated solvent, distillation is used to separate the solvent from the contaminants. The purified solvent may be a single solvent type or a blend of solvents, depending on the composition of the wastestream. In addition to simple decontamination, distillation principles may be used to separate solvent blends into their constituent solvent types.

Many organic industrial wastes can be purified for re-use using distillation methods. Waste solvents can be distilled for re-use in cleaning equipment in the painting, printing, plastics, adhesives, electronics and other industries. Phenol recovery from aqueous solutions is achievable through distillation.[6] Methylene chloride can be recovered from polyurethane waste.[2] Ethylbenzene can be separated from styrene and recovered.[2] Waste oil can be re-refined to produce commercial grade oil with the aid of distillation.[7]

Process Description

Distillation is the boiling of a liquid solution and condensation of the vapour for the purpose of separating the components. The process utilizes the differences in the boiling points of the components as the means of separation. If the solution to be separated contains only two components, one component concentrates in the condensed vapour (condensate) and the other in the residual liquid. For solutions containing more than two components, the less volatile components concentrate in the residual liquid and the more volatile ones concentrate in the vapour or vapour condensate.

The complexity of the distillation process varies with the number of components in the wastestream and the degree to which separation is required. The simplest form of distillation is batch distillation. Batch distillation is a single equilibrium stage operation and is carried out in a still in which the heat source is a steam jacket or a heating coil. The solution is boiled and vapour is driven off, condensed and collected until the desired concentration of product has been reached. If the desired product is the residual liquid in the bottom of the still, distillation proceeds until the "bottoms" concentration is at the required level.

Small-scale batch distillation units are commercially available for on-site reclamation of cleaning solvents such as those used in the painting and printing industries. These simple stills will remove impurities such as waste ink and paint from the cleaning solvent, however, they cannot separate the components of a solvent blend (see Figure 3). Most industries rely on solvent blends rather than a pure, single-type solvent for equipment clean-out purposes.

Those industries that require virgin-purity solvents, or precisely controlled solvent mixtures may choose to have their waste solvents undergo fractional distillation to separate them into component solvents. High-purity, single component solvents may be required by paint and ink formulators, and by hospital and science laboratories. There are many configurations that a fractional distillation unit may take. Typically, the fractioning column is a tall, cyclindrical column which contains material or internal structures to maximize contact between the liquid and vapour (see Figure 4).

Figure 3
Batch Distillation Unit

Contaminated liquid solvent is boiled in a still to evaporate solvent. Solvent vapour is condensed and may be collected as a liquid for re-use. If the desired product is the residual liquid in the bottom of the still, distillation proceeds until the "bottoms" concentration is at the required level.

Source: Unit Operations for Treatment of Hazardous Industrial Wastes, Noyes Data Corporation, 1978.

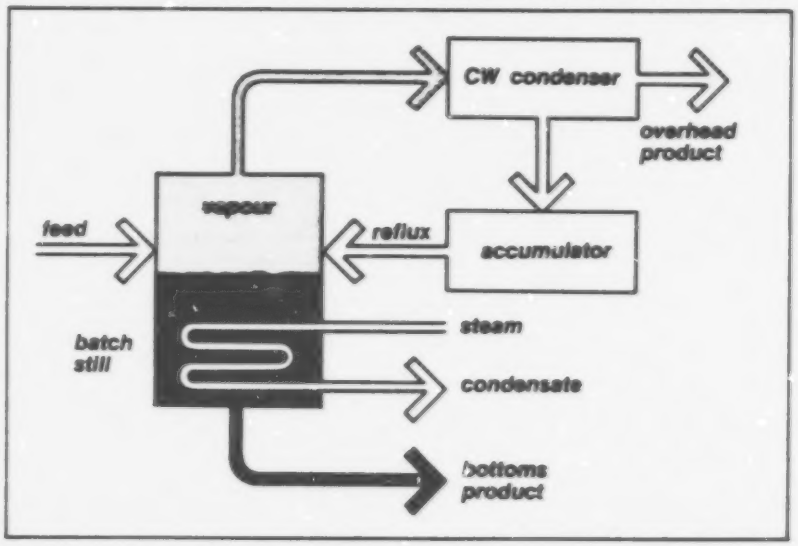
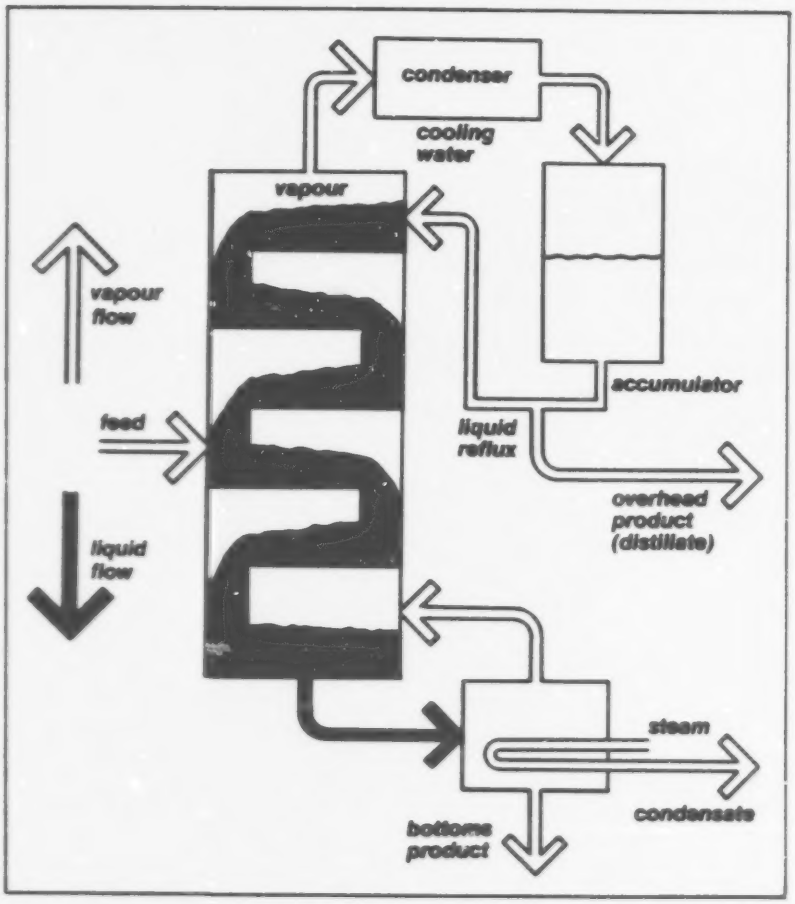


Figure 4
Fractional Distillation Process

Fractional solvent distillation is used to separate waste solvent blends into component solvents. During distillation, vapours of volatile solvents move up the distillation column while less volatile solvents still in the liquid form move down the column.
Source: Unit Operations for Treatment of Hazardous Industrial Wastes, Noyes Data Corporation, 1978.



Environmental Aspects

The treatment of waste organics by distillation does not create significant air and water pollution problems.[2]

The distillation of organic solvents requires the handling of large quantities of volatile and potentially toxic chemicals, however, emissions can be prevented by proper controls on tank vents and the distillation process itself.

Still bottoms are the residue remaining in the distillation unit after the volatile fractions have been vaporized and the useful, heavier fractions removed. Still bottoms may present a waste disposal problem because they contain impurities, tars and sludges, some of which may be toxic. The current disposal practice of landfilling these wastes is giving way to investigations in residue recovery as an auxiliary fuel, roofing material or low-grade paint, depending on the composition of the residue.

3. Electrodialysis

Electrodialysis technology has been in commercial operation for more than two decades, however, its application was directed primarily to the production of potable water from salt water, or to the production of salt from seawater. Hundreds of electrodialysis units are in use throughout the world, many of which have been in service for more than 15 years.

Electrodialysis is used industrially to remove mineral constituents or contaminants from process streams that contain large amounts of organic products. Examples of industrial use of electrodialysis include de-ashing of sugars, washing of photographic emulsions, demineralization of whey, desalting of food products such as whey, and in the chemical industry for a variety of solution enrichment or depletion purposes.

The current attention to waste recovery is making electrodialysis a suitable candidate for many of industry's wastewater problems. Pilot operations using electrodialysis have been successful in the recovery of plating rinses, desalting of sewage plant effluent, sulphite-liquor recovery, and recovery of hydrogen fluoride and ammonium fluoride effluents from glass and quartz etching facilities.[2,8,9] Future research and commercialization may see more widespread application of this technology to on-site industrial waste recovery and re-use.

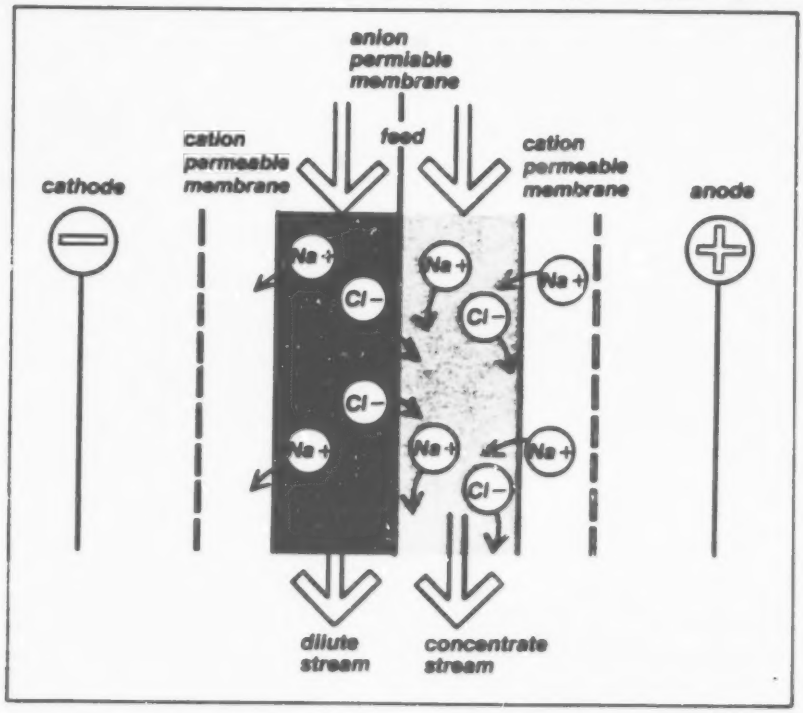
Waste Recovery Applications

Electrodialysis is widely applicable in the separation of an aqueous salt stream into dilute and concentrated streams. The purpose of the separation is to concentrate certain constituents in the wastestream for re-use, treatment or disposal. Typically, electrodialysis can separate a wastestream containing 1000 to 5000 ppm inorganic salts into a dilute stream that contains 100 to 500 ppm salt and a concentrated

Figure 5
Electrodialysis

Cations in the feed water show the same behaviour as sodium (Na^+) and anions the same behaviour as chloride (Cl^-). Under the action of an electric field, cation exchange membranes permit passage only of positive ions while anion exchange membranes permit passage only of negatively charged ions.

Source: Unit Operations for Treatment of Hazardous Industrial Wastes, Noyes Data Corporation, 1978.



stream that contains up to 10,000 ppm salt.[2] Electrodialysis technology is currently in use in waste developer recovery by the photo processing industry.

Process Description

Electrodialysis, along with reverse osmosis and ultrafiltration, are known as membrane technologies because they depend on membranes to selectively retain and permit passage of specific molecules. Unlike ultrafiltration and reverse omosis, separation in electrodialysis technology is induced by electrical current. Special synthetic membranes based on ion exchange resins are used which are permeable only to a single-charge ion. The construction of an electrodialysis unit is such that anion membranes are alternated with cation membranes in stacks of cells in series. Under the action of an electric field, cation exchange membranes permit passage only of positive ions while anion exchange membranes permit passage only of negatively charged ions. This results in the concentration or dilution of salts in alternate compartments (see Figure 5). The life of separation membranes is frequently five years, however, this varies with the type and volume of wastewater processed.

The use of electrodialysis to recycle spent developer baths from photo processors is similar. Commercially available electrodialyzers consist of cation exchange membranes stratified alternately, with a pair of electrodes installed at both ends. By applying a suitable direct current voltage, anions and cations in the developer solution compartments are attracted toward the electrode of the opposite charge. In the case of developer recycling, only halide ions such as bromide must be accumulated and eliminated, leaving other ions in the developer undialized and ready for re-use once the solution has been replenished.[10]

Environmental Aspects

Like other membrane separation methods, electrodialysis must be used in conjunction with additional recovery or treatment processes. There is some concern that electrodialysis may cause air pollution from the small amounts of chlorine gas generated at the electrodes when chlorides are treated.

4. Electrolysis

Electrolysis technology has been an important component in a variety of industrial processes over several decades. Its use as a waste recovery technology is also well established in many industries, and its significance as a recovery tool continues to grow as the costs of conventional disposal escalate. Examples of the use of electrolysis in industrial processing include the production of chlorine-caustic, metal refining and electroplating.

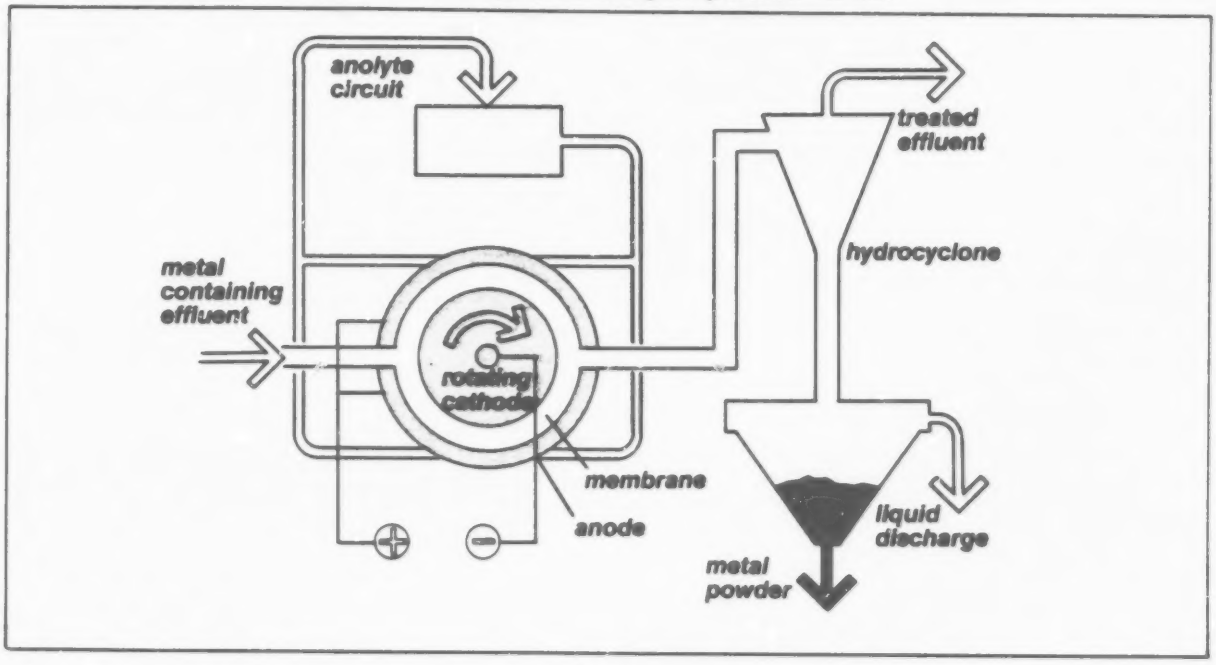
Waste Recovery Applications

Electrolysis is an important waste treatment and recovery technology. One of the major applications of this technology is in the recovery of heavy metals from wastewater. In the photo processing industry, silver is routinely recovered from spent fix through electrolytic means.

Electrolysis technology is applied to waste pickling solutions to recover metals.[11] In the copper industry, for example, waste pickling solutions are used to remove scale and oxides from freshly cast and hot worked copper metal. As the sulfuric acid bath accumulates

Figure 6
Electrolysis System

During electrolysis, oxidation or reduction takes place at the surface of conductive electrodes surrounded by wastewater. Metal ion present in the wastewater is reduced to metal itself at the cathode.
Source: "Heavy Metals Recovery Promises to Pare Water Clean-Up Bills," *Chemical Engineering*, December 22, 1975.



copper, it loses its effectiveness. By applying an electrolytic cell to plate the excess copper from the solution, copper is recovered, and the pickling bath retains its effectiveness over a longer period of time. Waste rinse solutions in which the metal ion concentration is very dilute may first undergo a separation or concentration process before the electrolytic recovery process is applied.

Another use of electrolysis in wastewater treatment is the oxidation of a dissolved species at the anode, such as in the destruction of cyanide. Electrolysis may be used indirectly to separate oil-water mixtures by generating tiny bubbles in a process known as electroflotation.[12]

Process Description

Electrolysis is based on the oxidation or reduction which takes place at the surface of conductive electrodes immersed in a chemical medium under the influence of an applied potential.[13] At the cathode (negative electrode) the metal ion is reduced to the metal itself ($M^{+} + e^{-} \longrightarrow M$) (see Figure 6).

In the case of electrolytic recovery of silver by photo processors, silver is deposited on the cathode in the form of silver plate with a purity close to 99%. The cathodes are removed periodically and the silver is chipped off and sent elsewhere for refining. To enchance the migration of metal ions to the cathode, it is common to engineer the recovery chamber such that the cathode rotates continuously, mixing the incoming metal-laden wastewater.

Environmental Aspects

Electrolytic systems may generate a potential air pollution problem due to the formation of gases such as hydrogen and chlorine at the electrodes.[2] Chlorine emissions, if significant, may be controlled with scrubbers.

5. Evaporation

Evaporation is a well-established waste concentration practice in widespread use throughout the industrial community. Some industries use evaporation technology to concentrate or separate wastes to permit re-use. Other industries use evaporation methods to dewater sludges prior to landfill disposal or incineration. Although evaporation is an expensive, energy-intensive process, it is used extensively in the treatment of hazardous waste because of the flexibility of the process and its proven success record. Evaporators have been used for many years in industrial recovery programmes and there are a number of systems available: rising film evaporators, flash evaporators using waste heat, submerged tube evaporators and atmospheric evaporators are all being used in commercial settings.

Waste Recovery Applications

Evaporation technology is widely used to separate water from inorganic solutions and slurries, though it is also used for concentrating sludges containing organic solvents. This technology is capable of handling liquids, slurries and sometimes sludges, both organic and inorganic, containing suspended or dissolved solids, or dissolved liquids where one of the components is essentially non-volatile.[2]

Evaporation is commonly used to dewater liquid radioactive waste to form a dry residue that is buried with other solid radioactive waste.[14,15] In the explosives industry, trinitrotoluene waste is concentrated by evaporation for disposal by incineration.[2] Some photographic chemical processing plants use exaporation procedures to dewater dye waste sludges.[2] In the pulp and paper industry, dilute "black liquor" is concentrated by heat from the steam recovery furnace prior to incineration for heat and chemical recovery.[16] Spent mash from molasses distillery processes is concentrated in a multi-effect evaporator and then incinerated for heat and chemical recovery.[2]

Waste types that can be handled by evaporation include heavy metals, radioactive materials, fluorides, chlorides, many hydrocarbons and halogenated hydrocarbons, amines, nitro compounds, explosives and dyestuffs.

Process Description

Evaporation is a physical separation process in which liquid is vaporized to separate it from a dissolved or suspended solid. Although evaporation resembles the distillation process, no attempt is made to separate the components of the vapour as in distillation.

Evaporators achieve resource recovery by distilling the wastestream until there is sufficient concentration of chemicals in solution for treatment, recovery or re-use. Because of their high energy requirements, evaporators are not used to concentrate highly dilute solutions. Water vapour produced during the evaporation process can be condensed and re-used, or released to the atmosphere. Condensing allows the recovery of some of the heat used in the evaporation process.

Evaporation equipment takes on many configurations. The most common evaporator type makes use of metal coils, tubes or jackets to maximize the surface area of heat transfer. Evaporators have undergone numerous design changes in past years to minimize energy requirements. Many evaporators operate under a vacuum to reduce the boiling point of the liquid, thereby minimizing energy consumption[17] (see Figures 7 and 8).

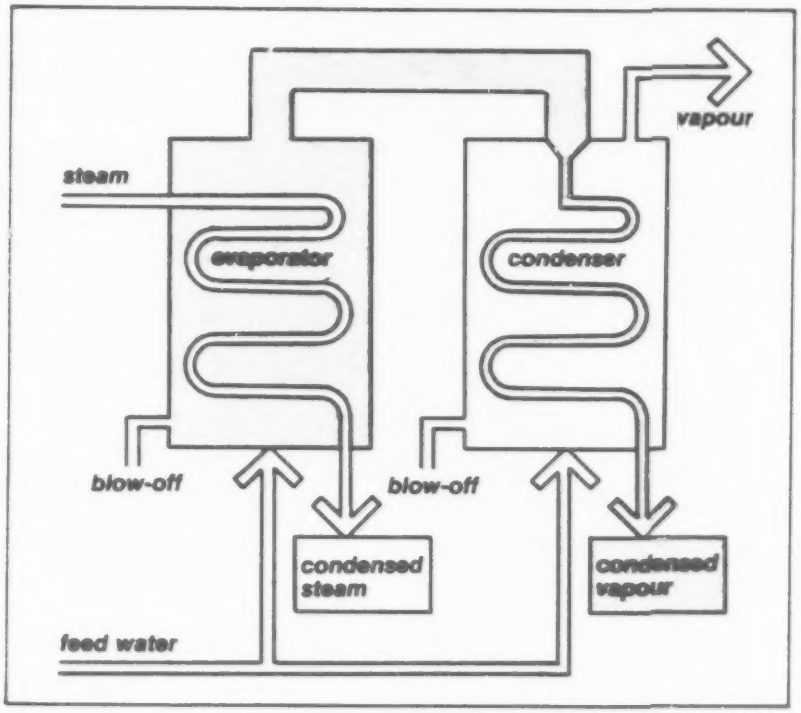
A common industrial evaporator is the vertical tube evaporator consisting of a relatively small flash chamber above a vertical arrangement of tubes within a cylinder.[18] Operating on the same principle as a smoke stack, the long tube evaporator gives high fluid velocity to the rising liquid and vapour within the tubes. The high fluid velocities promote high heat transfer efficiency between the evaporating fluid and the tube walls.

Another evaporator system is multiple-effect evaporation in which the vapour from one evaporator is used to provide heat for the next evaporator (see Figure 9). The significance of this design is that less energy is required to evaporate the same quantity of water compared with single-effect evaporators.[19] A company's decision on how many effects or evaporative stages to construct will be based on a trade-off between increased steam economy and the capital cost of additional evaporator equipment.

Another energy-conservative approach to evaporation is to use ponds exposed to the sun for concentrating brines or sludges.

Figure 7
Evaporator System

Wastewater is boiled to drive off water. The distilled water vapour can be condensed and re-used. The remaining wastewater is concentrated enough to permit re-use or treatment.
Source: Unit Operations for Treatment of Hazardous Industrial Wastes, Noyes Data Corporation, 1978



Solar evaporation ponds are widely used in California for dewatering hazardous wastes prior to land disposal. This technology is not suitable for climates where precipitation rates are high. As solar collector technology develops, an increasing number of companies are experimenting with sun-derived heat to provide auxiliary heat to plant operations.

Environmental Aspects

Air pollution problems are minimal in evaporation processes in which the material being evaporated is water. However, if the material to be concentrated contains volatile organic compounds such as solvents, it is necessary to condense these vapours for recovery, treatment or disposal.

Despite the energy-conservative feature of solar evaporation ponds, numerous potential problems exist. It is critical that solar evaporation ponds be located on impermeable terrain and constructed in a manner that ensures full retention of the waste material. Failure to do so may result in groundwater and surface water contamination. Solar evaporation ponds must be restricted in the types of wastes they contain to avert the emission of noxious and potentially toxic vapours in the air.

Figure 8
Long-Tube Vertical Evaporator

The long-tube vertical evaporator is one of many evaporator configurations.
Source: Chemical Engineering Handbook, McGraw-Hill, 1963

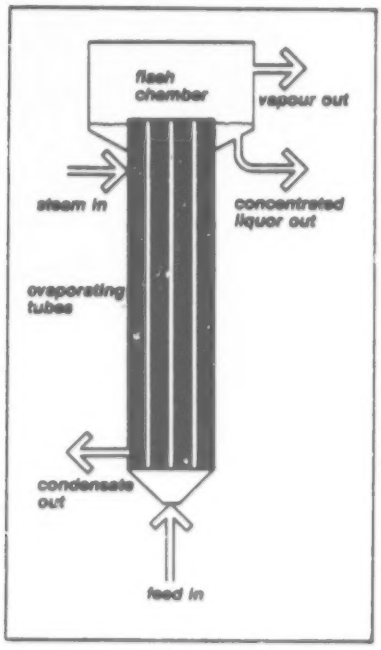
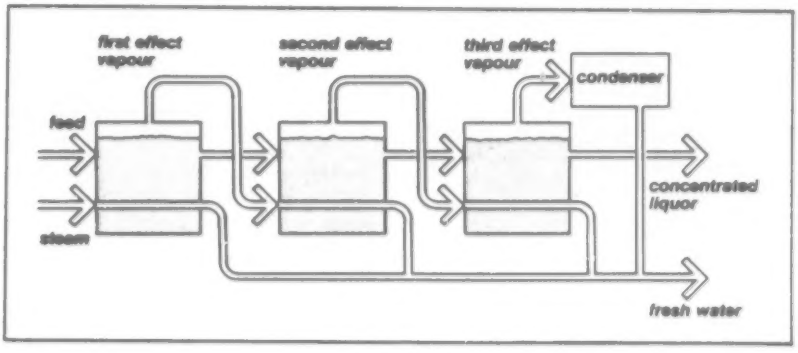


Figure 9
Multiple Effect Evaporator

By using several evaporators in series, the vapour from one evaporator can be used to heat the next evaporator and so on. The total heat consumption is less than for three evaporators functioning separately.
Source: Physical, Chemical and Biological Treatment Techniques for Industrial Wastes, U.S. Environmental Protection Agency, 1977.



6. Hydrolysis

Hydrolysis technology is as old as the making of soap. Known as saponification in the soap making industry, hydrolysis is the addition of alkali to hydrolyze heated fats to produce soap. A variety of hydrolysis reactions employing different reagents have been employed for years in the manufacture of organic materials. Although hydrolysis is not, as yet, widely used in the treatment of industrial wastes, the principles and equipment used in manufacturing applications are applicable to various waste treatment and recovery needs.

Waste Recovery Applications

Hydrolysis shows promise for the future treatment and recovery of industrial wastes. Some recovery applications in operation or demonstrated to be technically feasible follow.

Hydrolysis is used to recycle wastestreams in an organic chemicals plant.[20] For example, the manufacture of crufomate generates large quantities of wastewater and waste tar. Hydrolysis of the wastestreams yields an organic phase suitable for distillation and recycling, and an aqueous phase that may undergo biological treatment.

Another application of hydrolysis occurs in the treatment of acid sludge generated by the petroleum industry.[21] Hydrolysis of acid sludge yields a weak sulfuric acid fraction and a tarry acid oil layer. The recovery, concentration and re-use of the sulfuric acid portion can supply a refinery with more than half of its acid needs. The tar fraction can be recovered as an auxiliary fuel source.

The following applications of hydrolysis technology are technically feasible but not yet in widespread commercial use. Hydrolysis is suitable for the conversion of sludge to animal feed by converting activated sludge to a thick syrup which is high in protein, carbohydrates and vitamins.[22]

Hydrolysis processes can be used to decompose polyurethane foam waste to its constituent components to permit reprocessing into new polyurethane, or just recovery of the chemical components for resale.[33] Current research is demonstrating the feasibility of cyanide destruction through hydrolysis.

Hydrolysis is widely applicable to wastestreams from dairies, food industries, wool-scouring operations and antibiotics manufacture.[2] Hydrolysis of these wastestreams rich in carbohydrates may yield useful animal feed products.

Process Description

In general usage, hydrolysis refers to the decomposition brought about by water when hydrogen reacts with one component and hydroxyl reacts with another component. However, hydrolysis also refers to reactions in which water is not a reactant. For example, the addition of an alkali to solution and the subsequent formation of the alkali salt of an organic acid is known as hydrolysis. There are many classes of hydrolytic reactions. Most commercial hydrolysis processes operate at elevated temperatures and pressures to promote reaction.

Environmental Aspects

Despite the beneficial recovery aspects of hydrolysis, it must be recognized that certain hydrolytic reactions are capable of producing toxic byproducts. Use of this technology must be based on a clear understanding of the byproducts generated so that control measures may be initiated to avoid environmental hazards.

7. Ion Exchange

Ion exchange technology has been in use since the late 1800s in water softening and sugar crystallization procedures. By the late 1930s, the discovery of synthetic ion exchange resins resulted in their application to hydrometallurgy, deionization of water, and uranium processing and extraction. Ion exchange technology is also well developed and in commercial use to recover metals from wastestreams generated by the electroplating industry.

Ion exchange technology can be employed to remove a wide range of inorganic and organic contaminants including all metallic elements when present as soluble species, anions such as halide, sulfate, nitrate and cyanides, acids such as carboxylics, sulfonics and some phenols, amines and alkylsulfates.[2]

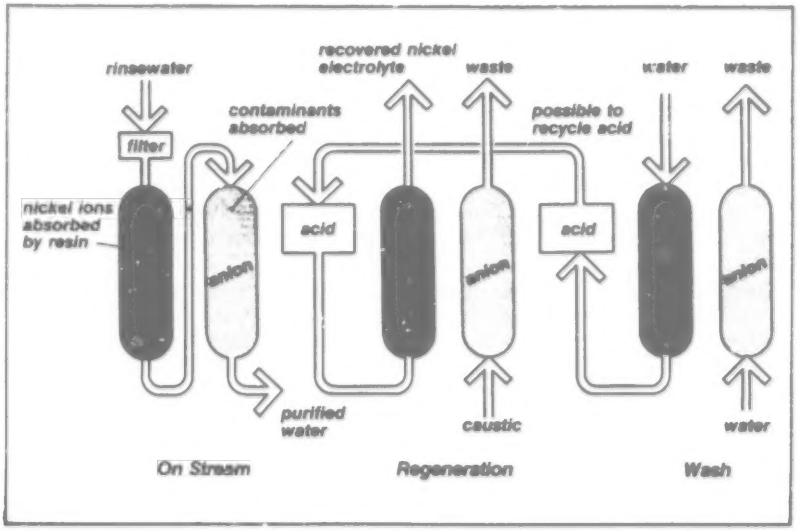
Waste Recovery Applications

Ion exchange technology is well developed in the electroplating industry[2,34] to remove ionic impurities from rinsewaster enabling re-use of the water. The impurities collected are suitable for recycling. This technology is gaining greater prominence among photo finishers to recover both water and silver from dilute waste rinsewaters.

Ion exchange technology is also employed to remove low concentrations of undesirable impurities from concentrated process streams. In such cases, the purpose is to recycle active materials while ridding the process bath of unwanted impurities. For example, in the cleaning of aluminum,[2,35] the phosphoric acid cleaning agent becomes contaminated with dissolved aluminum phosphate salts from the dissolution of the aluminum. Subjecting the contaminated cleaning bath to

Figure 10
Ion Exchange Nickel Recovery

Wastewater containing nickel ion contaminants is pumped through the cation exchanger where the nickel ions are retained by the resin. The wastewater then passes through an anion exchanger which retains anion contaminants. The purified water is ready for re-use. The cation exchanger is regenerated with sulphuric acid and a concentrated solution of nickel sulphate is eluted, leaving residual acid. It is possible to recycle the residual acid for re-use. The anion exchanger is regenerated with sodium hydroxide.



cation exchange ensures removal of the aluminum contamination and re-use of the bath.

Ion exchange technology is capable of separating organic materials and inorganic salts from industrial wastestreams. Highly saline liquid industrial wastes from food processing [26] have been desalinized by an ion exchange separation technique known as ion exclusion. In this type of separation, the sodium chloride is excluded by the resin while the non-ionized organic material can penetrate the resin.

Pilot demonstrations indicate that ion exchange is applicable to the recovery of chromium from cooling tower blowdown waters.[27] Ion exchange is also suitable for the removal of cyanide which occurs in some photo processing wastes.

Another promising development is the use of cation exchange technology to recycle metal pickling wastes.[28] Copper and steel pickle liquors, which result from an acid cleaning process, can undergo ion exchange to remove contaminants and permit re-use of the acidic cleaning solution.

Future research and commercialization of synthetic resins promise to extend the application of ion exchange technology to an even wider range of wastestreams.

Process Description

Ion exchange is a process for separating dissolved inorganic or organic substances from an aqueous liquid. This may entail the general or selective removal of heavy metals from dilute aqueous wastestreams, or the removal of select contaminants from more concentrated process baths.

The contaminant-laden liquid is passed through a bed containing a natural or synthetic resin. The resin exchanges ions with the inorganics in solution, resulting in the removal of inorganics from the solution and their attachment to the resin column (see Figure 10).

The wastestream is passed through the resin column until the ion exchange resin no longer effectively removes the contaminant. Once the resin bed is saturated with contaminant species, it is necessary to regenerate the resin by rinsing the contaminants from the resin with a concentrated brine or acid solution. The resin is restored to its original effectiveness and the contaminants may be recovered and recycled.

To ensure the effective operation of the ion exchange unit, it is important to remove any suspended solids prior to exchange that might otherwise plug the exchange bed.

Environmental Aspects

Commercially available ion exchange units tend to be closed systems and as such present no major air pollution problem. Because the regenerant solutions may be strong acids and bases, proper handling practices must be followed to avert spills or discharges. Although the purpose of many ion exchange units is to recover select metals for re-use, those systems which use ion exchange to collect hazardous wastes for further disposal must do so in an environmentally acceptable manner.

8. High-Gradient Magnetic Separation

High-gradient magnetic separation is a relative newcomer to waste recovery practices. Although not commercially attractive except in those instances where the recovered metal is of sufficient value to justify investment for its recovery, future research and development may enhance commercialization of this waste separation technology.

The predominant industrial use of high-gradient magnetic separation is in the purification of kaolin clay to remove a small unwanted magnetic fraction.[29] Another processing application is in the removal of impurities from iron and other ores.[30] Although magnetic separators capable of removing highly magnetic particles have existed for some time, high-gradient magnetic separation extends the efficacy of magnetic separation to include particles that are only weakly magnetic.

Waste Recovery Applications

Pilot plant trials are underway to apply high-gradient magnetic separation to coal desulphurization, water purification and the removal of flue dusts in air streams from blast furnaces. Potentially treatable waste forms include aqueous and non-aqueous liquids, slurries and dry powders. Waste types not amenable to high-gradient magnetic separation include sludges, tars and gases. Wastes suitable for this separation technology should flow easily through a relatively open filamentary matrix or be finely divided.

High-gradient magnetic separation appears to be best suited for the removal of magnetic wastes present in low concentrations in a liquid wastestream. Paramagnetic elements and compounds are removable by magnetic separation. Non-magnetic suspended solids may be removed from a contaminated stream if they associate with a magnetic floc which can be added to the wastestream. Dissolved material in water may be removed by magnetic separation if it co-preciptates with a ferric hydroxide gel in a wastestream.[31]

Process Description

The interest in high-gradient magnetic separation technology is spurred by the fact that separation speed and efficiency is considerably enhanced over ordinary filtration methods, and at lower costs and energy requirements.

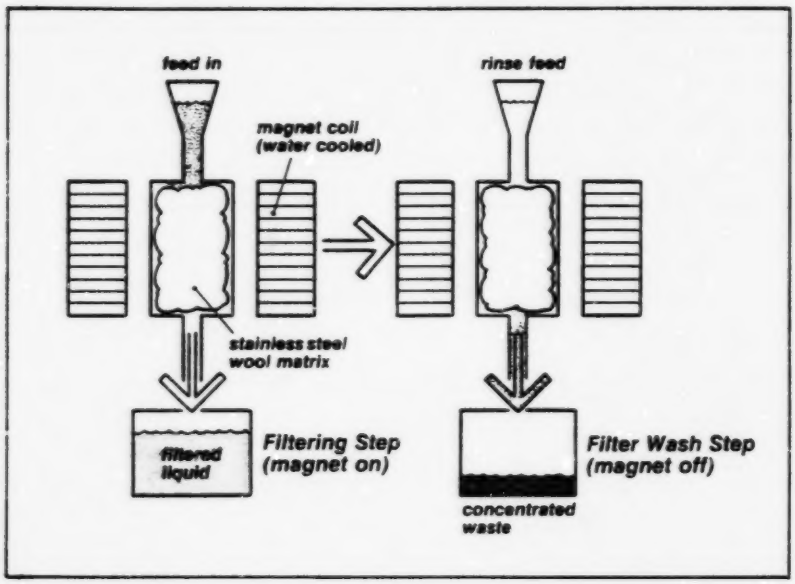
The high-gradient magnetic separation process makes use of fine ferromagnetic filament material containing 95% void space as occurs in compressed steel wool. Magnets capable of generating high-intensity fields are placed around the steel wool chamber. As the wastestream passes through the magnetic field in the chamber,

Figure 11
High-Gradient Magnetic Separation

1. ***Magnetic impurities collect on the steel wool as the wastewater passes through the magnetic field.***

2. ***The magnet is shut off and the steel wool is rinsed free of adherent particles.***

Source: Unit Operations for Treatment of Hazardous Industrial Wastes. Noyes Data Corporation, 1978.



impurities collect on the steel wool matrix by magnetic attraction. Metals and other magnetic impurities may be recovered by shutting off the magnet and washing the steel wool matrix clean of the adherent particles (see Figure 11).

Environmental Aspects

From a materials and energy conservation aspect, the optimum use of high-gradient separation is as a separation technology in conjunction with material recovery. The separation process itself appears to generate no serious environmental problems. However, if material recovery is not designed into the installation, great care must be taken to properly dispose of the sludge collected by washing the filter free of its impurities.

9. Solvent Extraction

Solvent extraction, a process for removing organic substances from aqueous or organic solutions, is used in both commercial processing and waste treatment. Commercial operations include the manufacture of lubricating oil from crude oil in which saturated paraffins are extracted with such solvents as phenol, furfural, propane and benzene; upgrading gasoline by separating aromatics from low-octane paraffins with the solvent diethylene glycol; the extraction of sulphur compounds from gasoline; the manufacture of fine chemicals and pharmaceuticals; and the refining of vegetable oils and fats.[32,33] Much of the solvent extraction technology currently used in manufacturing is directly applicable to the treatment and recovery of organics from aqueous wastestreams.

Waste Recovery Applications

Solvent extraction is applicable to the removal of organic compounds from aqueous and organic wastestreams. It is used in conjunction with other unit processes such as distillation or stripping to further purify selected solvents for re-use.

Although not in widespread use, solvent extraction has been demonstrated to be successful in the recovery of phenol and related compounds from aqueous wastes as generated by petroleum refineries, coke ovens and phenol resin plants.[34,35] The extraction process reduces phenol concentrations from 5% down to levels of a few ppm.

Extraction technology has also been applied to the recovery of halogenated hydrocarbons such as methylene chloride from an aqueous wastestream.[2]

An example of the extraction of a solvent from an organic wastestream concerns the reclamation of Freon® solvents.[2] The wastestream contains oil, Freon® and acetone. After distillation to separate the oil fraction, an extraction process is used to recover Freon® from the remaining Freon®/acetone mixture. Many research projects are under way in the United States to investigate solvent extraction as a viable waste recovery process.

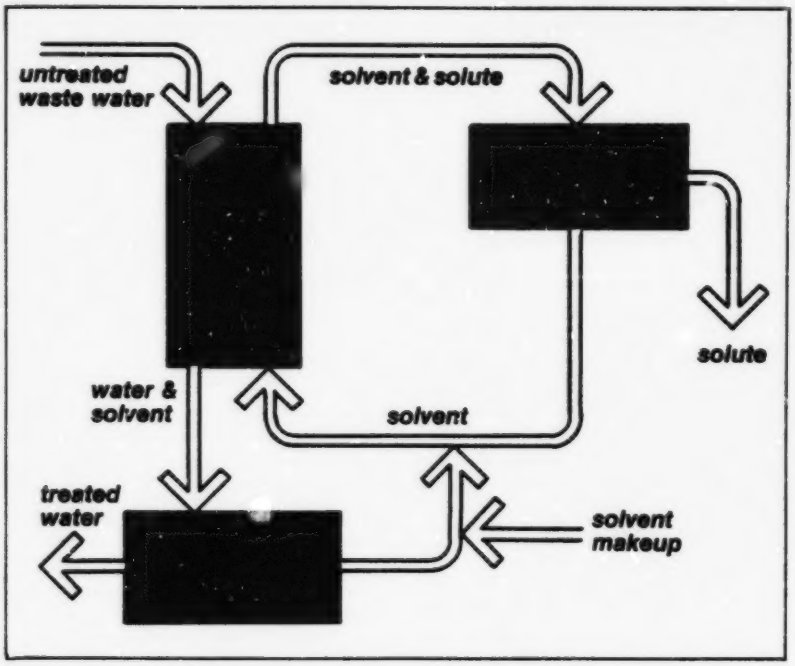
Process Description

Solvent extraction is the separation of select organic substances from a liquid solution by contact with an immiscible liquid. Separation of the liquid solution will result only if the original liquid solution distributes itself differently between the two liquid phases.

A solvent is added to the wastestream that does not dissolve in the wastestream. The mixture is agitated, enabling the added solvent to extract those organics in the original wastestream which have an affinity for it. Separation of the immiscible solvent from the wastestream is followed by distillation, stripping or adsorption to

Figure 12
Solvent Extraction of Wastewater

A solvent is added to wastewater to extract residual solvent in the wastestream. The solvent and solute undergo separation through distillation, stripping or adsorption.
Source: "Wastewater Treatment by Solvent Extraction," *Canadian Journal of Chemical Engineering* 49(6).



separate the organic contaminants from the extracting solvent. The solvent extraction process yields a treated solvent-free wastestream and a re-usable solvent stream (see Figure 12).

Environmental Aspects

There is potential for solvent loss through fugitive solvent emissions, however, this loss is minimal if proper extraction methods are employed. Solvent extraction is usually conducted to achieve material recovery for resale or re-use, and as such does not tend to generate large quantities of waste requiring further disposal.

10.
Reverse Osmosis

Although the principle of reverse osmosis has been understood for centuries, it was not until the late 1950s that researchers built the first reverse osmosis units. In the short 30 years since its cumbersome prototype was developed, reverse osmosis technology has undergone a dramatic transformation to become one of industry's most trim, efficient and versatile waste treatment systems.

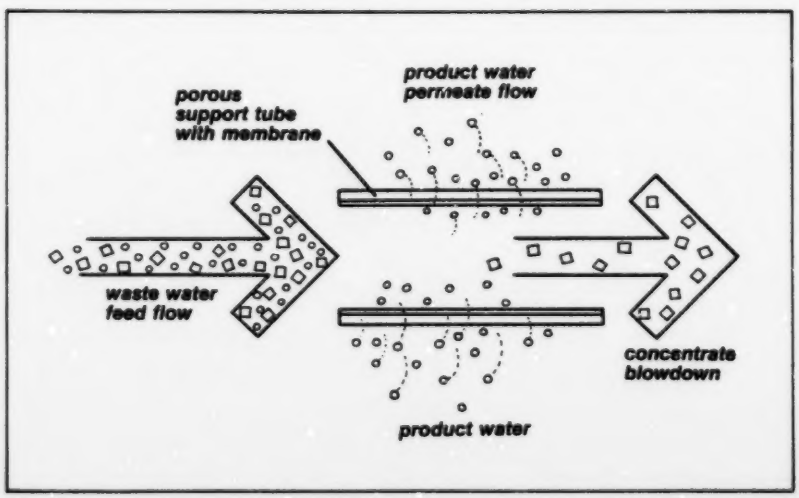
Waste Recovery Applications

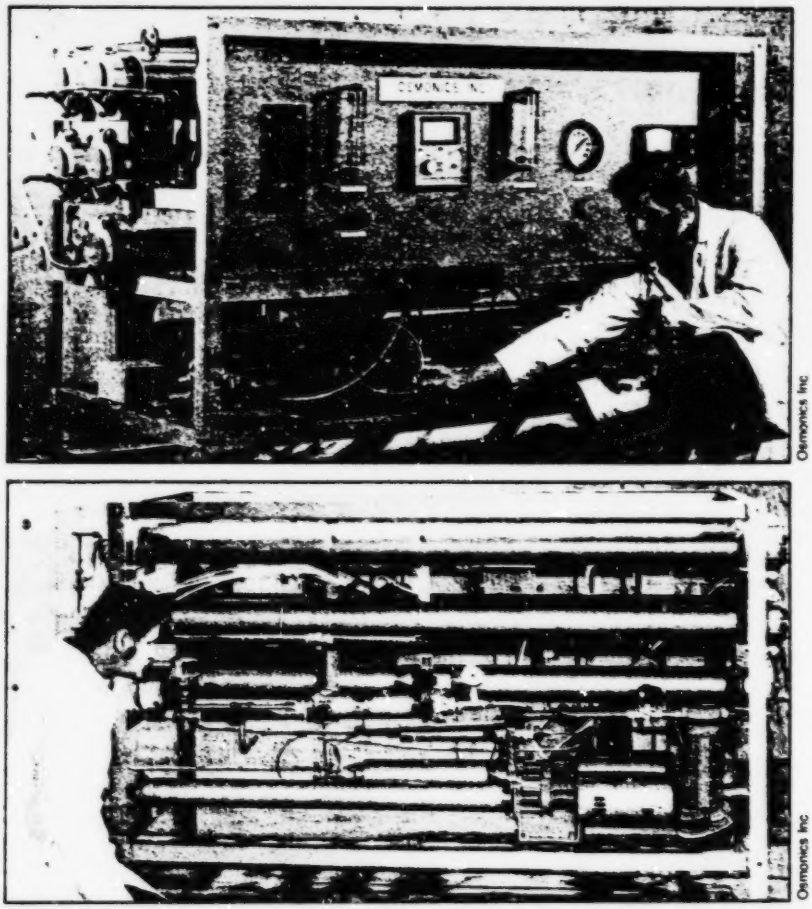
Reverse osmosis is applicable to the separation of dissolved ionic and non-ionic components from water solutions. Typically, the concentration of incoming wastewater is in the range of 500 ppm to 20,000 ppm although solutions containing up to 10% of the dissolved component can be processed.[2]

The types of wastestreams suitable for processing are limited by the ability of the plastic membranes to withstand the destructive nature of a given wastestream. Although aqueous

Figure 13
Reverse Osmosis Process

Wastewater is pumped under pressure through a semi-permeable membrane which permits the solvent (water) to pass but retains the dissolved components.
Source: Desalting Handbook for Planners, Bureau of Reclamation and Office of Saline Water, May 1972.

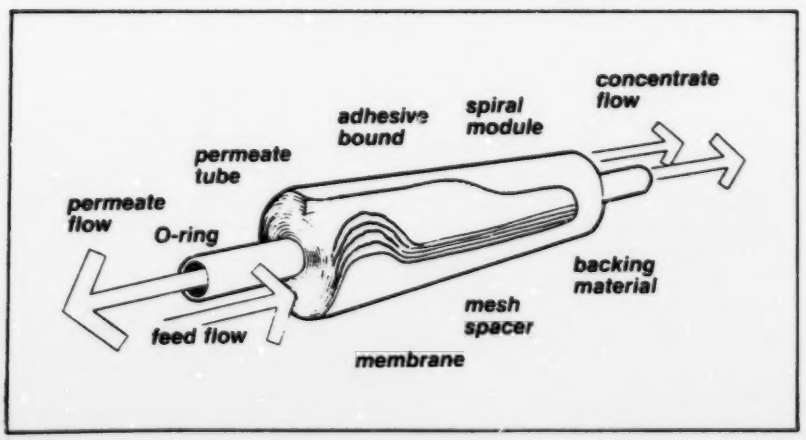




Front and back view of a reverse osmosis/ultrafiltration membrane separation system.

Figure 14
Reverse Osmosis Module

Reverse osmosis modules commonly consist of membranes wrapped around the permeate tube in a scroll configuration.
Source: Unit Operations for Treatment of Hazardous Industrial Wastes, Noyes Data Corporation, 1978.



streams with dissolved organics may be processed by reverse osmosis, pure organic streams usually deform plastic membranes. Similarly, strong acids and bases cannot be fed to reverse osmosis units. Reverse osmosis is well suited to accept many ionic compounds, including heavy metal solutions.

Reverse osmosis is widely used in chemical processing, in the preparation of pure water for industrial manufacturing and processing,[36] in preparation of rinsewater for use in semiconductor and electronic manufacturing, for reclamation of electroplating chemicals and water,[37,38] and in sugar reclamation in the food industry.[2]

Process Description

Reverse osmosis is based on a semi-permeable membrane which permits only certain components of solution to pass, and a driving force to separate these components at a useful rate. High pressure pumping in conjunction with a semi-permeable membrane permits passage of the solvent, which is usually water, but not the dissolved components of a solution.

Reverse osmosis results in a concentration of dissolved components on the high pressure side of the membrane while the water passing through the membrane is relatively pure (see Figure 13). The concentrated stream is allowed to flow out of the system and is known as the blowdown stream.

Although cellulose acetate was commonly used as the membrane material in the past, some units today make use of nylon membranes which permit operation at high pH values. Reverse osmosis units vary in how the membranes are arranged to maximize the contact areas.

The reverse osmosis module shown in Figure 14 shows a scroll configuration which contains a high percentage of membrane area per volume and is very easy to replace. The membrane with a synthetic backing is wrapped around the permeate tube and sealed around the edges.

Environmental Aspects

Virtually no air emissions or solid wastes result from a reverse osmosis operation. The process yields two streams, one, a concentrated stream, and the other, a relatively pure water stream. It is common to recycle the constituents in the concentrated stream, however, if a concentrated stream containing potentially hazardous constituents is improperly disposed, serious environmental pollution may result.

11. Ultrafiltration

Ultrafiltration, like reverse osmosis and electrodialysis, is a membrane separation technology. Ultrafiltration resembles reverse osmosis in that pressure is applied to a solution to force water across a semi-permeable membrane, however, unlike reverse osmosis, the passage of soluble material across the membrane depends only on its molecular size.

Waste Recovery Applications

Ultrafiltration is used to concentrate high molecular weight components of a waste solution for recovery or disposal, and to produce a decontaminated effluent for water re-use or discharge. The process is applicable to both homogenous solutions and colloidal suspensions which are difficult to separate by conventional filtration means.

Ultrafiltration technology is highly versatile and applicable to a wide range of industrial waste recovery needs. Some of the current commercial applications of ultrafiltration include the recovery of polyvinyl alcohol sizing from textile wastewaters,[39] paint recycling from an electrodeposition painting process, [40] the recycling of indigo from spent indigo dyebath as in textile dyeing,[41] protein recovery from cheese whey, [42] and the concentration of oil from metal machining, rolling and drawing.[43]

Other promising uses of ultrafiltration technology include pulp mill waste treatment, industrial laundry waste treatment, protein recovery from soy whey, product recovery in pharmaceutical and fermentation industries, and sugar recovery from orange juice pulp.[2]

Figure 15
Membrane Ultrafiltration Process

Wastewater is pumped under pressure to the semi-permeable membrane which permits passage of small molecules but retains the large ones.
Source: Unit Operations for Treatment of Hazardous Industrial Wastes, Noyes Data Corporation, 1978.

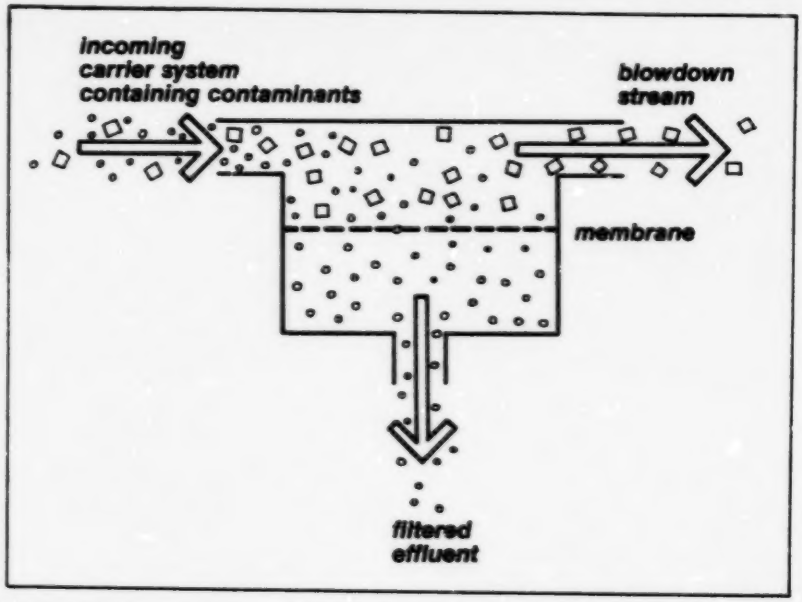
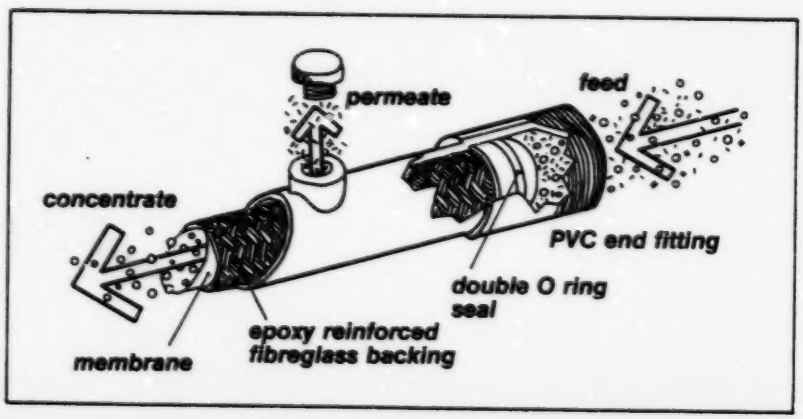


Figure 16
Fibreglass Reinforced Ultrafiltration Module

This diagram depicts another configuration for an ultrafiltration module. A membrane film is cast onto the inside of a porous fibreglass-reinforced epoxy support tube. The support tube is one inch in diameter by 10 feet long and fits into the permeate collection shell.
Source: Abcor Inc., Wilmington, Massachusetts.



Process Description

Ultrafiltration of a wastestream results in two streams, one, a concentrated stream containing high molecular weight solute or colloids, and the other, a dilute water stream. A hydrostatic pressure is applied to the upstream side of a semi-permeable membrane.

High molecular weight species remain on the high pressure side of the membrane while water and small size molecules pass through the membrane (see Figures 15, 16 and 17). Ultrafiltration membranes come with various filter pore sizes for molecules ranging from molecular weights of 200 to 100,000. The membrane can be tailor-made as to what size of molecules it will allow to pass. Typically, suspended material and high molecular weight dissolved species such as colloids, protein, carbohydrates and synthetic resins are not able to cross the membrane. Low molecular weight solutes such as certain salts, sugars and organics can pass through the microporous membrane.

Ultrafiltration systems can operate under lower pressures than reverse osmosis systems and the typical membrane flux levels are 20 to 200 gallons/day/foot^2.

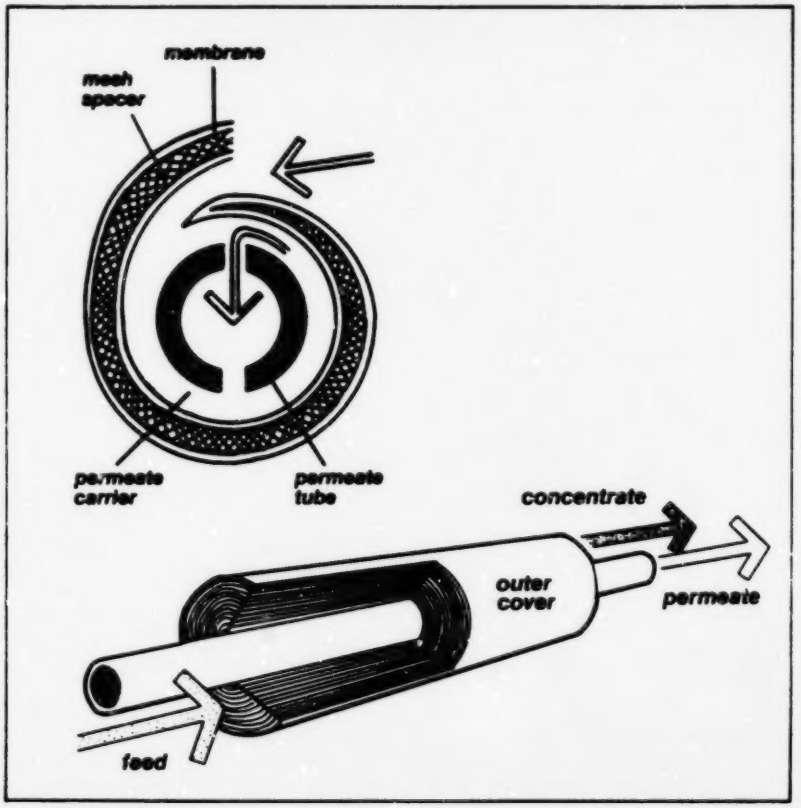
Environmental Aspects

Ultrafiltration is essentially a separation process. If hazardous constituents are present in the incoming wastestream, this technology serves only to concentrate these hazardous constituents for further recycle or disposal. In some instances, even the dilute filtrate will require additional treatment prior to sewering or discharge into a body of water.

Figure 17
Spiral Wound Ultrafiltration Module

Cut-away (upper figure) shows the spiral wound layers wrapped around the permeate tube. Cross-section (lower figure) shows the build-up of layers in this scroll configuration. The permeate flow arrows indicate the flow of pure water that passes through the membrane and spirals through the permeate carrier to the permeate collection tube.

Source: Osmonics Inc., Hopkins, Minnesota



POLLUTION PROBE

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The success of waste reduction and recovery should not detract from the need to adequately contain or destroy hazardous residuals. Even those companies active in industrial waste reduction, recovery and exchange generate a wastestream that requires disposal. Waste recovery and re-use operations can not recycle 100% of a company's wastestream. Recovery efficiency of a particular wastestream may be very high, but in the end, some residual waste generally remains.

In most instances in Canada, it is still cheaper for a company to dispose wastes by landfilling than it is to recover and re-use these waste materials. Those wastes that are recycled tend to be materials of high economic value such as semi-precious metals and select solvents. If waste disposal costs reflected the true costs of immobilizing wastes in perpetuity, it is probable that many of the wastestreams currently considered to be of marginal recycle potential would become economically feasible to recycle.

Two trends promise to steer industry along a path of greater waste reduction and recovery. One is the increasing value of raw materials, particularly the petroleum-based resources whose costs are spiralling. The second trend is the upgrading of legislation to end improper waste disposal practices. The upgraded dis-

posal requirements result in higher disposal costs. Both these factors are anticipated to accelerate waste recovery and environmental protection.

Disposal of a drum of hazardous waste cost American businesses $3 to $100 in 1980 (see Table 1). Any business confronted with a large bill to dispose of a single barrel of hazardous material is sure to give the waste recycle option serious consideration when resource recovery technologies are estimated to cost $10 to $40 per drum.[1] The disposal of hazardous wastes cost Canadian industry an average of $6 to $24 per drum in 1980[2] except for highly hazardous wastes such as PCBs and 2,4,5-T, for which accepted disposal facilities are lacking. For the most part, Canadian disposal costs tend to be lower than those in Europe and the United States.

The cost of burying waste will rise sharply as secure chemical landfill replaces sanitary landfill in the disposal of hazardous wastes. Based on 1980 prices, the cost of disposing wastes in a secure landfill in the United States was 4 to 40 times the cost of burying non-hazardous wastes in a sanitary landfill.[1]

In Canada, in the absence of widespread secure landfill facilities, much of industry's waste is co-disposed in sanitary landfills at a low cost. With the anticipated construction of sophisticated treatment and landfill facilities in Canada, it is highly probable that disposal costs will escalate significantly to reflect more accurately the true costs of proper disposal.

The technologies described in this chapter are applicable to the treatment and disposal of residual wastes remaining after waste reduction, recovery and exchange options have been exhausted. No single disposal option can meet the needs of all wastes. Some waste disposal methods are suitable only to organics, others only to inorganics and metals. Each method varies in environmental risks, efficiency and costs. Table 2 summarizes possible environmental impacts. The following major categories of waste disposal are discussed:

1. Biological Treatment
2. Physical-Chemical Treatment
3. Thermal Destruction
4. Radiation Destruction
5. Land Disposal

1. Biological Treatment

Biological treatment encompasses an assortment of technologies which use living organisms to decompose organic wastes into water, carbon dioxide and other simple organic and inorganic molecules.

Many conventional biological treatment processes have been in widespread use for decades by municipal sewage treatment plants and by industries generating wastestreams rich in biodegradable pollutants such as starch, cellulose, fats, oils and greases.

Industries using biological treatment processes include textile plants, tanneries, pulp and paper mills, refineries, breweries, petrochemical plants, steel companies and pharmaceutical plants.

Conventional biological treatment technologies such as activated sludge, trickling filter, aerated lagoons, waste stabilization ponds and anaerobic digestion have been the workhorses of the pollution abatement industry for years.

The application of biological treatment technologies to biodegradable wastes free of non-degradable contaminants yields a sludge suitable for composting and use as a soil amendment.

Although conventional biologi-

Table 1

Disposal Options: The Going Rate (1980) in the United States

	Price in U.S. Dollars	
	$/metric ton	$/drum
Sanitary Landfill	5-10	1-2
Secure Landfill		
Wastes which are not acutely hazardous, including sludges	20-90	4-18
Highly toxic, explosive or reactive chemicals	100-400	20-80
Incineration		
High BTU value, no acute hazard	50-300	10-60
Highly toxic, heavy metals	300-1000	60-200
Chemical Treatment		
Acids, alkalines	15-80	3-16
Cyanides, heavy metals, highly toxics	100-500	20-100
Resource Recovery	50-200	10-400
Deep Well Injection		
Oily wastewaters	15-40	3-8
Dilute toxic rinsewaters	50-100	10-20

Source: "Time for Decisions on Hazardous Wastes" *Industry Week*, June 15, 1981.

Table 2

Major Environmental Concerns of Various Waste Disposal Technologies

Waste Technology	Technology Type	Major Environmental Concerns
Activated Sludge	Biological	Disposal of sludge, particularly if contaminated with metals. Odours.
Rotating Biological Contactor	Biological	Disposal of sludge, particularly if contaminated with metals. Odours.
Trickling Filter	Biological	Disposal of sludge, particularly if contaminated with metals. Odours.
Aerated Lagoon	Biological	Disposal of sludge, particularly if contaminated with metals. Odours.
Stabilization Pond	Biological	Disposal of sludge, particularly if contaminated with metals. Odours.
Anaerobic Digestion	Biological	Disposal of sludge, particularly if contaminated with metals. Odours.
Composting	Biological	Adequate destruction of pathogenic organisms.
Landfarming	Biological	Danger of leachate migration.
Mutant bacteria	Biological	Possible development and escape of pathogenic strains.
Precipitation	Chemical Treatment	Disposal of sludge. Disposal of treated effluent. Safe transport and handling of reaction chemicals.
Solid-Liquid Separation	Physical Treatment	Disposal of sludge. Possible water pollution from residual contaminants in discharge stream.
Neutralization	Chemical Treatment	Possible air pollution, e.g. cyanide. Safe transport and handling of reaction chemicals. Additional pollutant loading of aqueous wastestream.
Chemical Oxidation and Reduction	Chemical Treatment	Safe transport and handling of reaction chemicals. Disposal of sludge. Disposal of treated effluent.

Table 2 (continued)

Waste Technology	Technology Type	Major Environmental Concerns
Chemical Dechlorination	Chemical Treatment	Safe transport and handling of reaction chemicals.
Liquid Injection Incineration	Thermal Destruction	Air pollution. Safe disposal of scrubber wastes. Transportation and handling hazard.
Rotary Kiln	Thermal Destruction	Air pollution. Safe disposal of ash and scrubber wastes. Transportation and handling hazard.
Fluidized Bed	Thermal Destruction	Safe disposal of ash. Transportation and handling hazard.
Multiple Hearth Incineration	Thermal Destruction	Air pollution. Safe disposal of ash and scrubber waste. Transportation and handling hazard.
Calcination	Thermal Destruction	Air pollution. Safe disposal of ash and scrubber wastes. Transportation and handling hazard.
Molten Salt Incineration	Thermal Destruction	Safe disposal of ash.
Plasma Arc Torch	Thermal Destruction	Air pollution. Safe disposal of ash and scrubber wastes.
Wet Air Oxidation	Thermal Destruction	Transportation and handling hazard. Water pollution unless wastestream treated further.
Cement Kiln	Thermal Destruction	Air pollution. Safe disposal of scrubber wastes. Transportation and handling hazard.
At-Sea Incineration	Thermal Destruction	Air pollution. Transportation and handling hazard.
Mobile PCB Destruction	Thermal Destruction	Air pollution. Transportation and safe handling of flushing solvent.
UV Radiation and Electron Beam Radiation	Radiation Destruction	Possible pollution from chemical intermediates.

Table 2 (continued)

Waste Technology	Technology Type	Major Environmental Concerns
Solidification	*Physical-Chemical*	*Air pollution during use of monomers and catalysts. Solidification product vulnerable to weathering. Leachate migration.*
Secure Landfill	*Physical*	*Air pollution. Leachate migration. Explosion hazard. Safe handling and transport of wastes to site.*
Retrievable Storage	*Physical*	*Air pollution. Explosion hazard. Safe handling and transport of wastes to site.*

cal treatment processes are environmentally benign with few negative impacts, their ability to adequately treat the effluents of some modern industrial processes is limited. Biological treatment systems do not destroy inorganics such as metals. Metal constituents and certain toxic organics can inhibit microbial decomposition or may accumulate unchanged in the sludge. Contaminated sludge must be dewatered and disposed of through incineration or secure landfilling. Segregation of wastestreams on the company premises permits the hazardous component to undergo special and cost-effective treatment while the biodegradable fraction is treated, composted and re-used as a soil conditioner.

Biological treatment technologies are summarized in Table 3. Most of these treatment methods are tried and tested technologies in existence for many years. The development of mutant bacteria to detoxify persistent chemicals is an emerging technology that is discussed in greater detail below.

Mutant Bacteria

The complexity and variety of industrial wastestreams has researchers sleuthing for "super bugs" able to degrade chemicals that defy traditional waste treatment. Thousands of strains of bacteria occur naturally in the environment. Bacterial strains differ in their ability to degrade specific chemicals.

There are two major approaches in the development of special pollution-eating bacteria. One approach, known as genetic engineering, makes use of recombinant DNA to modify the genetic information in bacteria. In genetic engineering research, genes responsible for degrading specific chemicals are spliced into other organisms to create new bacteria.

Despite the vast potential of creating versatile bacterial strains capable of detoxifying wastes, genetic engineering is viewed with concern. Genetic experimentation brings with it the fear that mutant bacterial strains may form that are hazardous to human health and environmental well-being.

A second approach in the development of special pollution-eating bacteria involves strain selection of mutant bacteria to concentrate selected characteristics into a new organism. Although selective breeding is less efficient than recombinant DNA in creating new microbes, it is perceived as less of a threat than genetic tampering.

Genetic engineering and selective breeding experiments have developed bacteria capable of detoxifying such resistant chemicals as PCBs, 2,4-D, 2,4,5-T, DDT, phenols, certain dyestuffs and oil spills.

Battelle Memorial Institute (Columbus, Ohio) is focussing on bacterial means of destroying DDT and 2,4-D. Researchers have transplanted the gene for 2,4-D degradation from a less active organism into a bacterium of the genus *Pseudomonas*. The resultant bacteria convert 2,4-D into harmless products such as carbon dioxide and water.[3]

Battelle researchers have identified a bacterium that attacks DDT by accumulating it inside the organism's cell. Although the bacterium does not detoxify DDT, it can be used to concentrate DDT residues in wastewater.

Dr. Chakrabarty, a researcher with the University of Illinois, has created a new strain of bacteria that degrades 2,4,5-T. A major drawback is the length of time required to destroy the waste. The bacterium takes 2 weeks to consume 1 mg of 2,4,5-T, however researchers are striving to cut the time required to 3 to 7 days.[4]

Chakrabarty has also identified a naturally occurring bacterium capable of breaking down PCBs and toluene.[4]

Research at SRI International (Menlo Park, California) is proceeding on bacteria that can inject and destroy the pesticide parathion, certain chemical intermediates and organic dyestuffs.

Table 3

Biological Treatment Technologies

Technology	Wastestreams Applicable	Description
Activated Sludge	Used for secondary treatment of dilute biodegradable wastestreams. Industrial applications include cannery, pulp and paper mill, refinery, brewery, steel plant, petrochemical and pharmaceutical wastes.	Micro-organisms break down dilute organic wastestream in a continuously aerated tank. Typical retention time is 6 to 24 hours. The wastewater is then clarified in a settling tank in which sludge is separated from the organic-free water. Treated water is discharged and a portion of the sludge from the clarifier is recycled back to the aeration tank to maintain a high microbial population. Major problem is the disposal of copious amounts of sludge, frequently contaminated with metals.
Rotating Biological Contactor	Biodegradable wastestreams.	Based on the same microbial decomposition principle as activated sludge systems. Equipment is designed to enhance the rate of waste treatment and to reduce the overall space requirements of the treatment complex. Microbial populations adhere to the slowly rotating discs which are in partial contact with the wastestream. The rotating discs carry a thin film of wastewater into the air where the efficient breakdown of organic wastes occurs. Sludge disposal is a concern.
Trickling Filter	Used for secondary treatment of aqueous wastes. Industrial applications include cannery, pharmaceutical and petrochemical wastes including oils, phenols, alcohols and sulfides.	Wastes are sprayed through the air to absorb oxygen and then allowed to trickle through a bed of crushed rock or other media that is covered with micro-organisms including bacteria, fungi, protozoa and sludge worms. A trickling filter system includes a final settling tank to remove biological residue sloughed off the filter media. Requires disposal of residual biomass.
Aerated Lagoon	Used for secondary treatment of aqueous biodegradable wastes. Industrial applications include textile, pulp and paper mill, cannery, refinery and petrochemical wastewaters.	Wastewater is retained in a large earthen lagoon containing a high microbial population. Mechanical aerators introduce oxygen into the pond and keep the wastewater well mixed. Unlike activated sludge systems which recycle sludge rich in microbes, sludge is not recycled in aerated lagoons. This necessitates a longer retention time, typically 2 days. Before the treated effluent is discharged, sludge is removed from the wastestream in a settling basin. The sludge requires periodic removal and disposal.

Table 3 (continued)

Technology	Wastestreams Applicable	Description
Stabilization Pond	Used to provide final polishing of treated wastewater. In other instances, used to partially degrade high-strength raw wastes prior to subsequent treatment.	Large shallow ponds are used to degrade residual contaminants in treated wastewater. Aeration is provided by the wind. Some stabilization ponds are deep enough to provide anaerobic decomposition at the lower levels. Stabilization ponds are not energy intensive, however land requirements are great and treatment time is long. Typical retention time may be 4 days. Sludge accumulates in the bottom of the stabilization pond.
Anaerobic Digestion	Used to treat sludges and high strength biodegradable aqueous waste. Industrial applications include high-strength food production and paper mill wastes.	Anaerobic digestion occurs in oxygen-free closed vessels heated to 35°C at which temperature bacterial decomposition is optimal. Microbial activity in the absence of oxygen results in methane gas, hydrogen sulfide, carbon monoxide and nitrogen. Sludge volumes are reduced considerably, and methane gas may be burned to provide process and plant heating.
Deep Shaft	Used for strong biodegradable industrial wastes such as brewery wastes.	In this aerobic process, the wastewater is oxidized in a 500-foot-deep shaft placed in the ground. There is good oxygen utilization because of better dissolution of the oxygen at the high pressures existing in the bottom of the shaft. Prior to oxidation in the shaft, the wastestream undergoes primary settling to remove sludge. Compared to other biological treatment methods, deep shaft treatment has a small land requirement.
Composting	Biodegradable sludges that are free of metal and other toxic contaminants.	Composting of biodegradable sludges may occur in the presence or absence of oxygen. Aerobic composting occurs more quickly and with less noxious odours than anaerobic composting. In aerobic composting, sludge is mixed with a bulking agent and turned periodically to ensure optimum oxygenation. Composted sludge is an excellent soil conditioner for agricultural uses. Sludges with moderate to high metal levels are unsuitable as soil conditioners and present a disposal problem.
Landfarming	Biodegradable wastes free of metal and other toxic contaminants. Industrial applications include meat packing wastes, organic chemical wastes and oily wastes from petroleum refineries.	Wastes typically are sprayed on top of a tilled field, and periodically ploughed to ensure ample aeration of the soil bed. Micro-organisms that occur naturally in the soil break down the organic wastes. Oily wastes from the petroleum refinery operations are applied at an average rate of 600 barrels per acre per year in southern U.S. climates.

Table 3 (continued)

Technology	Wastestreams Applicable	Description
Mutant Bacteria	*Specific bacterial strains can destroy specific wastes including 2,4,5-T, 2,4-D, PCBs, phenols, fats and greases, ammonia, cyanide and other degradable compounds.*	*Select microbial cultures resulting from genetic manipulation and selective breeding are commercially available to treat specific waste components. A major difficulty facing industrial users of microbial waste destruction techniques is the variability of the incoming wastestream. Large fluctuations in pH, temperature and metal content of the wastestream will kill the bacterial culture and render detoxification incomplete.*

Kenzo Tonomura, of the University of Osaka (Sakai, Japan), has isolated a strain of bacteria capable of degrading organic mercury compounds.[4]

The Chemical Engineering Department at Ohio State University is investigating cost-effective methods of removing phenol from a wastestream.

Established colonies of *Pseudomonas* bacteria can consume phenol at concentrations up to 300 ppm. Researchers at Ohio State demonstrated that the use of *Pseudomonas* bacteria in a semi-fluidized bed process can save up to 50% of the cost of conventional sludge processes for phenol removal.[5]

Several small companies are in the business of selling mutant bacteria to clean up wastewater, hazardous spills and digest solid wastes.

Major companies in the business include Polybac (Allentown, Pennsylvania), Worne Biochemicals (Berlin, New Jersey), Flow Laboratories Environmental Cultures Division (Englewood, California) and General Environmental Services (Cleveland, Ohio).[3]

The mutant strains sold by these companies can decompose materials such as aromatic hydrocarbons, fats and greases and ammonia. The mutants can handle thousands of time more material than their precursors.[3]

The use of mutant bacteria to mop up after chemical spills into the environment such as oil and toxic chemicals has been met with some reservation. Experts disagree on whether the use of mutant bacteria should be confined to a waste treatment facility, or whether new bacterial strains should be allowed to be dispersed directly into the environment.

2. Physical-Chemical Treatment

Physical and chemical treatment processes are used to detoxify or reduce the volume of industrial and municipal wastes. These treatment procedures are applicable to most inorganic wastes such as metal-laden discharge waters, and to some organic wastes such as oil/water mixtures.

A large segment of industry's hauled liquid waste includes aqueous wastestreams which are contaminated in varying degrees with metals and other inorganics. Because of the dilute nature of many of these hazardous wastes, the volume and subsequent transportation costs are high.

Transportation costs may be curtailed by concentrating the hazardous component of the wastestream prior to transfer. Technologies applicable to the concentration of wastes include neutralization, filtration, precipitation, sedimentation, flotation, membrane separation, reverse osmosis and evaporation.

Many waste concentration technologies are directly applicable as materials recovery and water re-use techniques. Physical/chemical recovery technologies include ultrafiltration, reverse osmosis, carbon adsorption, electrolytic recovery, distillation and others. Recovery technologies are discussed in detail in the preceding chapter, Waste Recovery Technologies.

Provincial and local governments establish permissible levels of industrial discharge into natural water bodies and sewers. The level of contaminants in industrial process waters may exceed local guidelines and standards. In order to comply with permissible pollution levels, many industries truck their waste to a treatment/disposal facility. In other instances, an industry may chose to pre-treat its wastewater using an assortment of physical-chemical means, and then discharge the treated effluent in a sewer.

The physical-chemical treatment methods described are mostly conventional technologies. Many are currently in use by industries and sewage treatment plants receiving combined municipal-industrial wastes. Treatment methods described include:

Precipitation
Solid-liquid separation
Neutralization
Chemical oxidation and reduction
Chemical dechlorination

Precipitation

Application

Many industries generating wastewaters high in dissolved solids use precipitation, flocculation and sedimentation as consecutive processes to treat the same wastestream. This technology, in industrial use since the 19th century,[6] is used widely to treat wastestreams containing soluble metals and colloidal hazardous substances.

The iron, steel and copper smelting industries routinely use precipitation to remove metals from pickling wastes. Precipitation techniques are also used in the metal finishing industries to remove toxic metals such as cadmium, chromium, and nickel from rinsewaters and discarded plating baths. The electronic industry removes copper from spent etching solutions. The inorganic chemical industry removes metals from a variety of wastestreams, again using chemical precipitation methods.[7]

Process Description

Precipitation and flocculation are characterized by the addition of chemicals to a wastestream to enhance the separation of the suspended solids or dissolved solids fraction from the liquid component.

Wastewater which contains dissolved solids must undergo chemical change before the dissolved solids are changed to a form in which they can be physically removed from the wastestream. In some instances, a precipitating agent added to the wastestream reacts directly with the dissolved contaminants to form an insoluble product. The insoluble product then undergoes settling or filtration.

Many precipitation reactions depend on pH changes through the addition of chemicals to convert dissolved contaminants to insoluble products. Another method is to alter the temperature of the wastestreams to increase the precipitation of contaminants.

Some wastestreams contain extremely fine suspended solids not easily filtered by conventional means. In such instances it may be preferable to add a chemical agent to cause these solids to form an agglomerated mass. Flocculation is a process by which suspended particles are combined into larger particles or "flocs" that can be readily separated by gravity sedimentation.

An example of precipitation involves zinc chloride and sodium sulfide, both of which are highly soluble in water. When these two chemicals are combined, the zinc ions and sulfide ions combine to form zinc sulfide. Zinc sulfide is insoluble in water and may be removed from the wastestream by simple settling methods, leaving sodium chloride in the solution.

Most chemical precipitation processes used by industry today involve the addition of virgin chemicals including lime, metallic salt cations and sodium hydroxide. The use of virgin precipitating agents is both expensive and demanding of industry's supply of chemical resources. Instead of relying on solely virgin chemicals, some industries have learned to precipitate one wastestream with another wastestream. In the case of sodium sulfide precipitating out the zinc in zinc chloride to produce insoluble zinc sulfide, it is common to find separate zinc chloride and sulfide wastestreams originating from different industries. Matching the two wastestreams forms a zinc sulfide precipitate which happens to be a useful, saleable fertilizer.

Precipitation technology has been in existence for many decades. However, as the thrust for cleaner industrial discharges continues, it is questionable whether conventional precipitation technologies can meet the increasingly stringent emission requirements facing industry in North America.

Solid-Liquid Separation

Solid-liquid separation processes are simple, relatively inexpensive technologies designed to physically separate the solid and liquid components of wastestreams.

In treating liquid wastestreams, solid-liquid separation techniques are used to remove suspended and settled solids from the wastewater prior to discharge or further treatment. Solid-liquid separation processes will not remove dissolved solids from the wastewater, unless a precipitation process precedes.

In treating sludges for disposal, solid-liquid separation methods are used to remove excess water from sludges prior to ultimate disposal. Four major types of solid-liquid separation include:

Sedimentation,
Flotation,
Filtration,
Centrifugation.

Sedimentation

Sedimentation is a process in which material heavier than the wastestream settles out by gravity in a special tank or holding pond.

Chemical coagulating or flocculating agents may be added to help collect the particles together to speed settling in those wastestreams where solids such as colloidal particles remain finely dispersed in a liquid, making them resistant to rapid settling.[7]

Flotation

Dissolved air flotation is used to remove certain solids, greases and emulsified oils difficult to remove by simple sedimentation. Excess air is dissolved in the wastestream under pressure and then released to the bottom of the flotation tank at atmospheric pressure, resulting in the formation of many tiny bubbles. The solids in the wastestream are carried to the surface by minute air bubbles, and subsequently removed by skimming.

Flotation is used by the refining, meat packing, paint, poultry processing, paper milling and baking industries to achieve a 80 to 99% removal of suspended and floating solids.[7]

Filtration

Filtration is based on the movement of a wastestream through a filtration medium which functions to trap suspended

solids while permitting the liquid component to pass through unchanged. In instances where water-soluble contaminants exist in the wastestream, it may be necessary to treat residual soluble contaminants after filtration.

Two major applications of filtration processes include the removal of suspended solids from a wastestream, and the dewatering and subsequent volume reduction of sludges.

Filtration technology has been in use for decades, and as such has witnessed the development of many technology refinements and variations. Filtration is used in conjunction with other treatment technologies. For example, it may be necessary to filter a wastestream to remove suspended solids before that wastestream can undergo further treatment such as ion exchange or carbon adsorption.

Filtration procedures differ in whether the filtered solids are trapped and accumulate on the surface of the filtration medium, or whether the filtered solids are entrapped within the pores or body of the filtration medium.[6]

Diatomaceous earth is an example of a filtration medium used to trap solids within the pores of the medium. Diatomaceous earth results from the gradual deposition of aquatic organisms known as diatoms on the bottom of a lake. Diatoms consist of silica shells with four tube-like projections. Diatomaceous earth, mined from old lake bottoms, is used as a filtration medium because of its excellent porosity.

Some oil recycling companies, for example, use diatomaceous earth to remove dirt and other particulates from used oil.

Other common filtration media are silica sand, garnet sand, perlite, carbon and various synthetic materials. Some of the more widely used filtration techniques are described in Table 4.

Centrifugation

Centrifugation is an alternative technique for dewatering sludges and for concentrating precipitated solids in a wastestream.

Two types of centrifuges are the sedimentation centrifuge and the filtration centrifuge.

Table 4

Common Filtration Types

Type	Description
Granular media filtration	*Wastestream flows through a bed of granular material, either by gravity flow or under pressure. The filter bed may be regenerated periodically by back flushing the solids from the bed using a reverse flow of washwater.*
Filter presses	*Filter presses are used to dewater sludges or slurries. Fabric positioned over a porous metal plate forms the filtration medium. The liquid passes through the fabric under pressure. The solids become concentrated within the dewatering chamber, forming a dried sludge cake.*
Leaf filter	*Pressure leaf filtration is used to remove suspended solids. The filters consist of a series of frames over which a fabric filter cloth is stretched. A thin layer of filter aid material such as diatomaceous earth, perlite or activated carbon is placed on the filter fabric. Liquid passes through the filter media under pressure and is discharged through the pores of the leaf filter. Filter restoration includes periodic removal of the accumulated solids and clogged filter aid materials. With each clean-out, a new layer of filter aid materials is applied to each filter leaf.*
Rotary vacuum filtration	*Rotary vacuum filtration is used for the dewatering of slurries and sludges. Filtered cloth covers a drum-shaped steel cage. The revolving drum is partially immersed in sludge or a waste slurry. A vacuum applied to the inside of the rotating drum sucks liquid through the filter cloth, leaving a layer of relatively dry solids on the outside of the drum. As the drum rotates, solids are scraped off the surface of the filter cloth before the cloth is reimmersed in the slurry* ***(see Figure 1).***
Cartridge filters	*Cartridge filters are used to remove solids from a wastestream with relatively low solids loading, as occurs in previously treated wastestreams. Although cartridge filters have only limited capacity to store solids, they are popular because of their convenience and ease of cleaning. Spent cartridge filters are replaced with new cartridges.*

Source: Hazardous Wastes in Northern and Western Canada. Volume 2. Prepared for Environment Canada. December 1980.

A sedimentation centrifuge is used to accelerate the settling of solids in a wastestream. The wastewater is rotated rapidly in an enclosed chamber, resulting in the build-up of sediment on the inside wall of the chamber.

A filtration centrifuge operates on the same principle, however, in this instance, the rotating chamber composed of filter cloth permits liquid to move out through the cloth. Dewatered sludge collects on the inside of the filter cloth and is removed for disposal.

Neutralization

Application

Neutralization is in use in a wide spectrum of industries which generate acidic or basic wastewater[8] (see Table 5).

The purpose of neutralization is to prepare a wastestream for discharge into a sewer. Otherwise, if a company sent pulses of acidic or alkaline wastes into the sewer system, it is highly probable that bacteria responsible for wastewater decomposition at the centralized sewage treatment facility would be destroyed. In many instances, neutralization functions as just one step in a sequence of treatment processes.

Metal cleaning operations in which scale, oxides and other impurities are removed from metal surfaces by immersing them in inorganic acids such as sulfuric, hydrochloric or phosphoric acid result in an acidic wastestream known as pickling liquor.

Process Description

Neutralization is a common chemical treatment process in which an acid is mixed with a base in order to neutralize the wastestream to a pH approaching 7. Typically, mixing acidic wastewater with a base, or mixing alkaline wastewater with an acid results in water and a salt. Resultant salts that are insoluble in water form a sludge that must be eliminated prior to discharge of the neutralized effluent.

Most industries still use virgin chemicals to neutralize their wastestreams. However, as chemical costs increase and treatment costs spiral, some industries are saving themselves thousands of dollars by substituting another industry's wastestream to neutralize their wastes.

Figure 1
Rotary Drum Vacuum Filter

A vacuum applied to the inside of the rotating drum sucks liquid through the filter cloth, leaving a layer of relatively dry solids on the outside of the drum.

Source: Hazardous Wastes in Northern and Western Canada, Vol. 2, prepared for Environment Canada, December 1980.

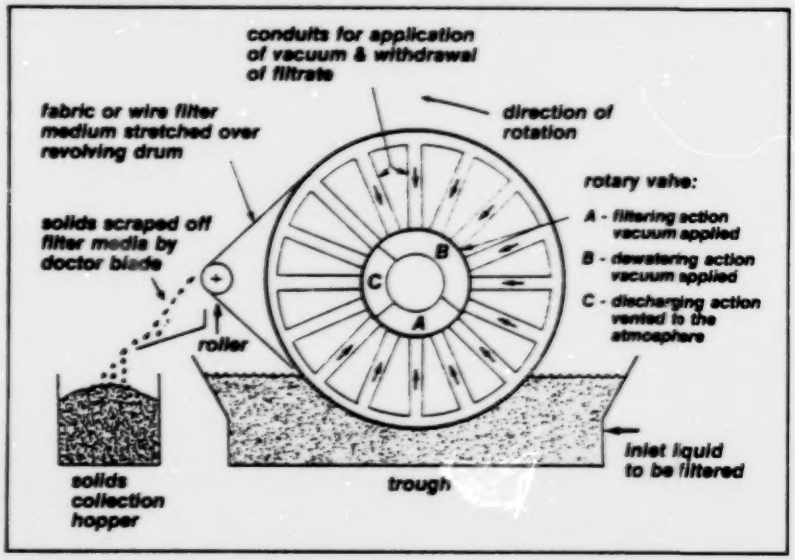
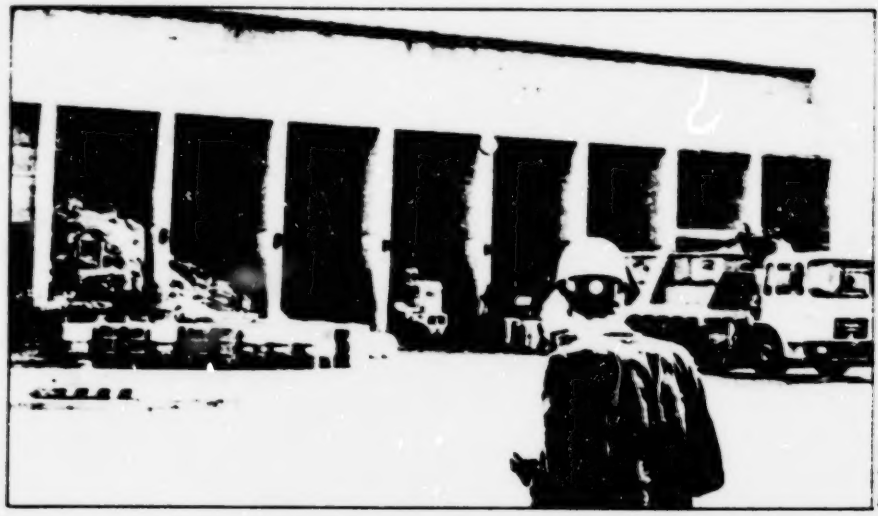

conduits for application of vacuum & withdrawal of filtrate
fabric or wire filter medium stretched over revolving drum
direction of rotation
rotary valve:
A - filtering action vacuum applied
B - dewatering action vacuum applied
C - discharging action vented to the atmosphere
solids scraped off filter media by doctor blade
roller
solids collection hopper
trough
inlet liquid to be filtered

Table 5
Industries Using Neutralization

Industry	pH Range of Wastewater
Beverages	Acidic and Basic
Cement, Lime & Concrete	Basic
Dairy Products	Acidic and Basic
Fertilizer	Acidic and Basic
Fruits and Vegetables	Acidic and Basic
Grain Milling	Acidic and Basic
Industrial Gas Products	Acidic and Basic
Inorganic Chemicals	Acidic and Basic
Leather Tanning	Acidic and Basic
Metal Finishing	Acidic
Non-Ferrous Metals (aluminum)	Acidic
Pharmaceuticals	Acidic and Basic
Plastics	Acidic and Basic
Pulp and Paper	Acidic and Basic
Steel Pickling	Acidic
Textiles	Basic

Source: Pretreatment of Pollutants into Publicly Owned Treatment Works. U.S. EPA, October 1973.

Waste unloading docks at the Kommune-Kemi waste treatment facility in Denmark. Wastes are received in containers of all sizes and types at this treatment facility. Bulk storage of liquid wastes until time of treatment and disposal.



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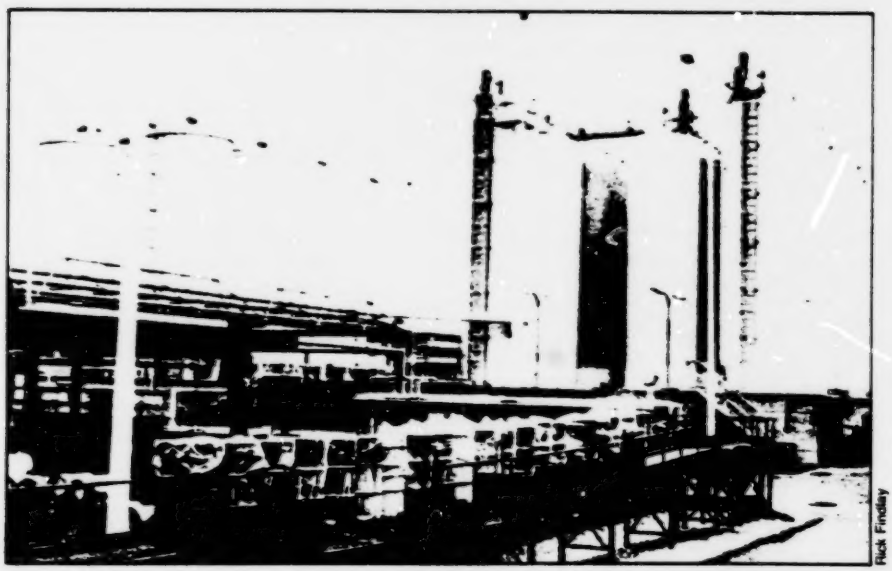

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Alkaline wastes are neutralized by the addition of hydrochloric or sulfuric acid. Sodium hydroxide, calcium hydroxide, calcium carbonate and quicklime are used to neutralize acid wastes. Blending acid and alkaline wastestreams is often feasible because it eliminates the cost of purchasing neutralizing agents.[9]

Despite the promise of merging different wastestreams together to achieve neutralization, several caveats must be heeded. Wastestreams typically contain small amounts of heavy metals and other dissolved contaminants. Toxic components must be reduced to acceptable levels by precipitation, sedimentation and filtration before the neutralized effluent is released to a sewage treatment plant.

The successful mixing of wastestreams depends on full knowledge of wastestream constituents as well as a sound understanding of chemistry. It is critical that reaction products be predicted and evaluated prior to the physical mixing of the wastestreams. Otherwise, unexpected toxic gases may result. For example, the acidification of wastes containing sulfide or cyanide salts may result in the production of hydrogen sulfide or hydrogen cyanide gases.

Chemical Oxidation and Reduction

Application

Chemical oxidation is suitable to aqueous wastestreams containing inorganic and organic wastes. Typical hazardous waste constituents that can be detoxified by an oxidizing agent include cyanides, pesticides, phenols, aldehydes, aromatic hydrocarbons and sulphur compounds.

The electroplating industry is a significant generator of cyanide wastes. The cyanide in solution can be oxidized with chlorine gas or hypochlorite solutions, yielding nitrogen and carbon dioxide. Potassium permanganate and hydrogen peroxide have also been successful in detoxifying aqueous cyanide wastes.[7]

Process Description

Chemical oxidation processes depend on a chemical reaction to detoxify hazardous wastes. The hazardous wastestream is subjected to an oxidizing agent such as chlorine, ozone, sodium hypochlorite, calcium hypochlorite, potassium permanganate, hydrogen peroxide and nitrous acid. Chemical bonds are broken and the toxic material is converted into simpler, less toxic chemicals.[7]

In Europe, a cyanide destruction system in use acidifies cyanide waste to hydrogen cyanide. The hydrogen cyanide is then stripped from the wastestream in a trickle-flow counter-current packed tower (see Figure 2). Incineration of the off-gases yields water, carbon dioxide and nitrogen. Extreme precautions must be taken to prevent highly toxic hydrogen cyanide gas from escaping into the atmosphere during acidification and stripping.[6]

Joint research by Dr. Donald Sawyer of the University of California and Dr. Julian Roberts of the University of Redlands has resulted in another advance in chemical oxidation technology. The two California scientists discovered that a negatively charged form of oxygen known as superoxide could break down many chlorinated hydrocarbons (excluding PCBs) into relatively harmless substances.[9]

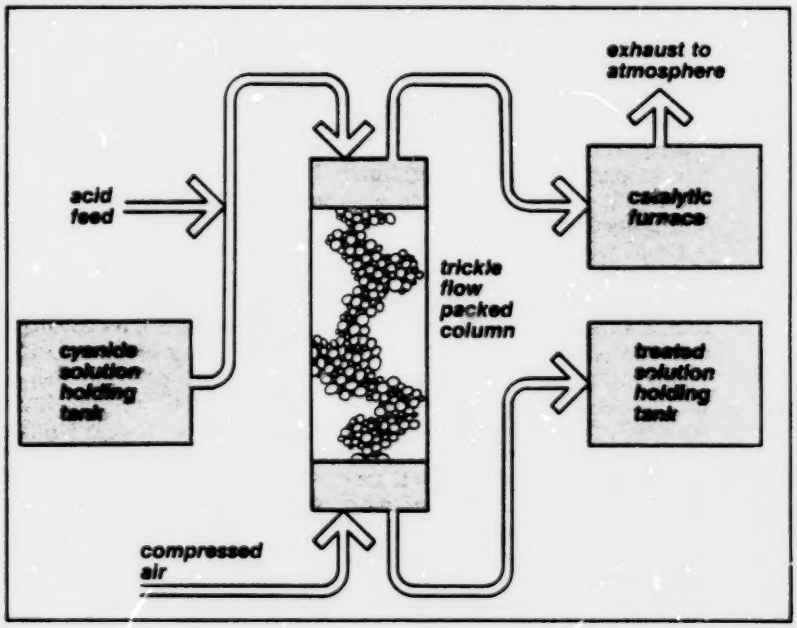
When an electrical current is passed through chemical waste in a solution, the oxygen content is transformed into superoxide. The halogenated molecules present in the waste solution are then converted to harmless substances such as carbonates. The process is not suitable for aqueous wastes. Bench scale studies have demonstrated the rapid degradation of chlorine compounds such as carbon tetrachloride, chloroform, methylene chloride and DDT.[9]

Chemical reduction is applica-

Figure 2
Daester-Fairtec Cyanide Destruction System

Cyanide waste is acidified to hydrogen cyanide. The hydrogen cyanide is then stripped from the wastestream in a trickle-flow counter-current packed tower.

Source: Hazardous Wastes in Northern and Western Canada, Vol. 2, prepared for Environment Canada, December 1980.



ble in the detoxification of metals in solution.

Chromium typically present in electroplating and tanning wastestreams as hexavalent chromium (VI) is highly toxic. In the reduced state, trivalent chromium (III) is much less hazardous and can be precipitated for removal.[6] Common reducing agents include sodium bisulphite, iron, aluminum and zinc compounds.

Chemical Dechlorination

Application

Chemical dechlorination is suitable to non-aqueous wastestreams contaminated with chlorinated organics.

Among the more common chlorinated hydrocarbons are polychlorinated biphenyls (PCBs), tetrachloroethylene (perc), chlorobenzene, pentachlorophenols, dichlorophenols, vinyl chloride (VC), methylene chloride, trichloroethane, carbon tetrachloride and an assortment of pesticides such as aldrin, heptachlor, 2,4-D and 2,4,5-T.

Process Description

Chemical dechlorination refers to a group of emerging technologies which can be used to strip chlorine atoms from highly chlorinated toxic compounds to produce a non-toxic residue.[7] A highly reactive chemical reagent is introduced into the chlorinated hydrocarbon liquid to chemically break apart the stable chlorinated molecules into simpler and less toxic constituents.

Proponents of chemical dechlorination cite many reasons why a chemical destruction system is superior to incineration of chlorinated hydrocarbons. Unlike incineration processes, there are no emissions from the totally enclosed chemical dechlorination systems.[7] The use of chemical dechlorination to detoxify transformer oils contaminated with PCBs ensures that they are not burned up and wasted, but rather cleaned for re-use. Unlike many incineration systems, chemical dechlorination technology can be portable. By detoxifying wastes on-site, transportation risks and costs are eliminated.

A major concern with chemical dechlorination involves the hazardous nature of the chemical reagents employed. Extreme caution is necessary when handling the metallic sodium reagents. Given the high reactivity of sodium in water and air, it is critical that no air enter the reaction vessel.[7]

In 1980, the Goodyear Tire and Rubber Company (Akron, Ohio) used a proprietary process to treat 40,000 gallons of PCB-contaminated heat-transfer fluids. PCB levels were reduced from 82 ppm to less than 10 ppm. Goodyear uses a metallic sodium reagent called sodium naphthalene tetrahydrofuran to chemically destroy PCBs.

Sunohio Inc. (Canton, Ohio) has developed a chemical dechlorination process using a different reagent to destroy PCBs. In recent tests, Sunohio successfully reduced the concentration of PCBs in transformer oil from 225 ppm to 1 ppm.[7] Acurex Corporation (Mountain View, California) is another company striving for the commercialization of a chemical dechlorination process.

Despite the current preoccupation with PCB destruction, chemical dechlorination technology is anticipated to be directly transferable to the destruction of other chlorinated hydrocarbons such as pesticides.

3. Thermal Destruction

Thermal destruction technologies are used to break down organic hazardous wastes into less toxic constituents, ideally CO_2 and water. Heat is applied to the waste in an enclosed chamber to cause the disintegration of the molecular bonds of the organic material. Equipment design varies according to whether liquid, sludge or solid organic wastes are destroyed.

Thermal destruction technologies are classified into two broad categories: incineration and pyrolysis.

Incineration

Incineration technologies are based on the combustion of wastes in the presence of excess oxygen. The products of incineration include water, carbon dioxide and ash. In addition, most incineration processes yield non-combustible residuals such as metal oxides and other inorganics. The non-combustible residuals may escape with the flue gases or may accumulate in the ash. The type and quantity of non-combustible residuals remaining after incineration depend upon the degree and type of contamination of the organic wastestream.

Pyrolysis

Pyrolysis technologies are based on the combustion of wastes in an oxygen-deficient environment. Organic wastes are broken down into a range of lower molecular weight, simpler organic molecules and an ash. Pyrolysis is of interest because it not only detoxifies organic wastes, but does so in a manner in which process end products might be recovered for re-use as chemical feedstocks or as a fuel.

Since the pyrolysis of some organics may yield products which are more toxic than the original waste, it should be used very carefully with well-defined waste feedstocks. Chlorinated materials, for example, would not be a good feedstock to a pyrolysis system.

Energy Content of Wastes

Rich Wastes

Organic wastestreams are differentiated on the basis of the energy content of the waste. Wastes are described as rich wastes or lean wastes. Rich wastes are those which are high enough in heating value to sustain combustion on their own, except for the ignition of the fuel. Wastes with a heat value of 7000 Btu per pound are characterized as rich wastes. Flame temperature must be at least 2000°F to ensure complete oxidation.[10]

Lean Wastes

Lean wastes are those below 7000 Btu per pound. Such wastes require additional fuel or an energy-rich wastestream to sustain combustion temperature.[10] Some organic wastestreams are considered lean because they contain a high water content. In such cases, it is advantageous to reduce the water content before incineration.

Organic sludges are characterized as having a high solids content, typically 20% or more by weight, and having sufficiently high heating value to support combustion. Disposal costs for incinerating organic wastes vary depending upon the additional heat required to burn them and on the ash content requiring further disposal.

Although landfill is still the cheapest and most widely used disposal method in North America, there are many thermal destruction technologies available to industry. Many of these technologies have been in use for many years, and as such are "proven" technologies. Emerging technologies that show great promise for specific problem wastes include the plasma arc torch, molten salt incineration, the wet air oxidation process and pyrolysis.

The following technologies are discussed in greater depth on the following pages:

- Liquid injection incineration
- Rotary kilns
- Fluidized bed
- Multiple hearth incineration
- Calcination
- Molten salt incineration
- Plasma arc torch
- Wet air oxidation
- Cement kiln
- At-sea incineration
- Mobile PCB destruction

Liquid Injection Incineration

Application

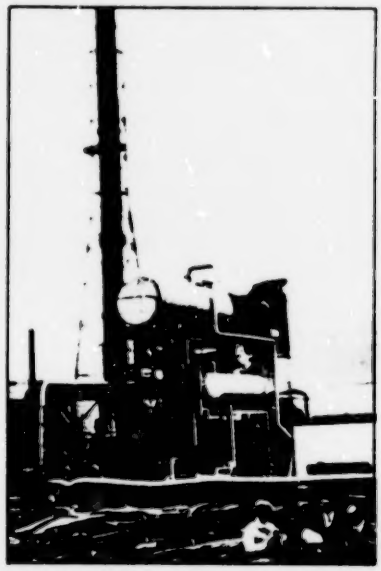
Liquid injection systems are used to burn pumpable organic liquids. Wastes must be removed from the transport container and fed into the combustion chamber via a nozzle. This incineration system cannot dispose of drums or non-pumpable wastes.

Highly viscous wastes may be heated to an easily pumpable viscous state. Other methods of lowering the viscosity of the organic wastestream include emulsifying the waste or dissolving it in a lower-viscosity waste.[6]

Liquid injection incinerators have been used to destroy a variety of wastes including phenols, PCBs, still and reactor bottoms, solvents, polymer wastes, herbicides and insecticides.[7] They are generally unsuitable for burning organic wastes contaminated with heavy metals, high-water-content wastes, or materials with a high inorganic content.

In Europe, injection incinerators have been used to destroy halogenated organic liquids under carefully controlled combustion temperatures and residence times.[6] When burning halogenated organics, it is critical that appropriate gas scrubbing devices are used to trap escaping halogens such as chlorine.

Liquid injection incinerators are probably the most commonly used type of incinerator for hazardous waste destruction in North America. An example of a Canadian liquid waste incinerator is found near Sarnia, Ontario. Operated by Tricil (Corunna, Ontario), this incinerator destroys non-halogenated organic liquids. The absence of pollution control equipment on the Tricil liquid



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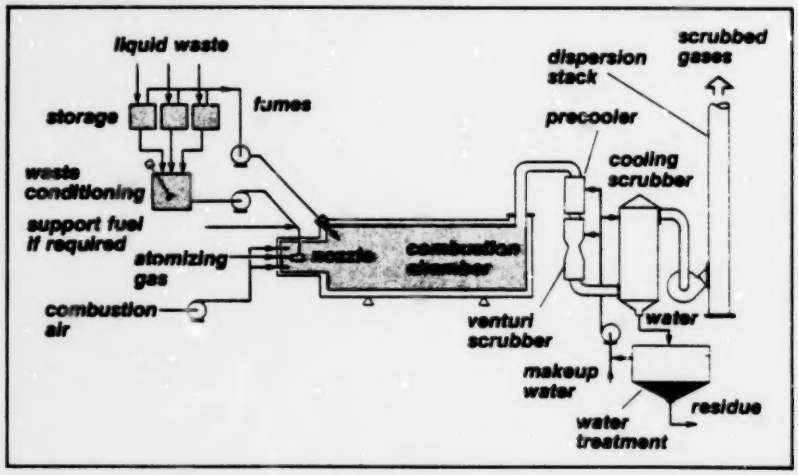
Liquid injection unit for the incineration of liquid wastes. This unit lacks scrubber equipment for air pollution control.

Figure 3
Liquid Incineration

Liquid wastes are preheated and blended with other combustible materials as necessary. The wastestream is then injected in an atomized form into the combustion chamber.

Source: Hazardous Wastes in Northern and Western Canada, Vol. 2, prepared for Environment Canada, December 1980.



waste incinerator makes it necessary to limit the concentration of inorganics and halogenated organics present in the wastestream.[2]

Process Description

A typical liquid waste incinerator consists of one or more atomizing nozzles and a refractory-lined combustion chamber. The liquid wastes are usually pre-heated and blended to upgrade their combustibility and pumpability. The wastestream is then injected in an atomized form into the combustion chamber (see Figure 3). Complete combustion is obtained only if the waste is adequately atomized and mixed with air.

Typical combustion chamber temperatures range from 650 to 1650°C with exhaust temperatures maintained constant at 750 to 1200°C.[2] Incineration temperature and residence time of the incinerated waste vary with the needs of specific wastes to ensure complete combustion.

Rotary Kiln

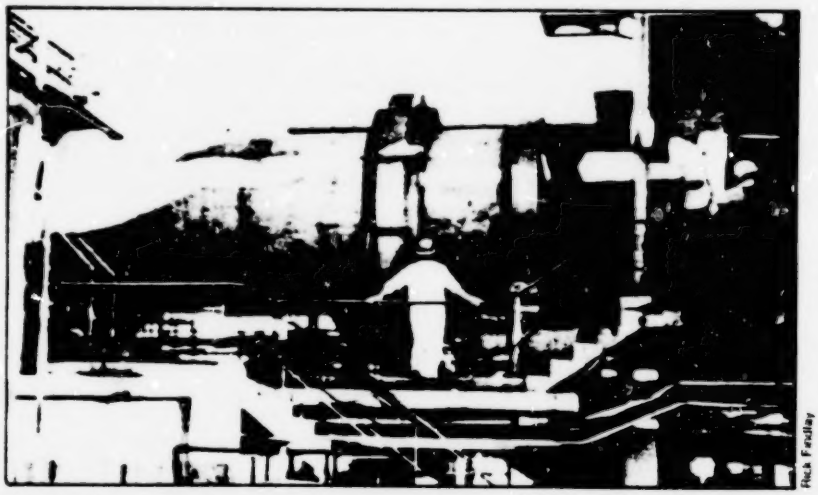
Application

The rotary kiln offers greater flexibility than a liquid waste incinerator because of the wider range of wastes it can incinerate. A rotary kiln can be used to incinerate organic liquids, slurries, sludges, solids and even drummed waste.

Existing installations of rotary kilns include units operated at the following locations: Rollins Environmental Services (Baton Rouge, Louisiana; Logan, New Jersey; and Houston, Texas); Dow Chemical (Midland, Michigan); Eastman-Kodak (Rochester, New York); 3M (Minneapolis-St. Paul, Minnesota); GSB (Ebenhausen, West Germany); and KomuneKemi (Nyborg, Denmark).

Process Description

A rotary kiln incinerator uses a slowly revolving steel cylinder lined with fire bricks for the primary combustion chamber. The



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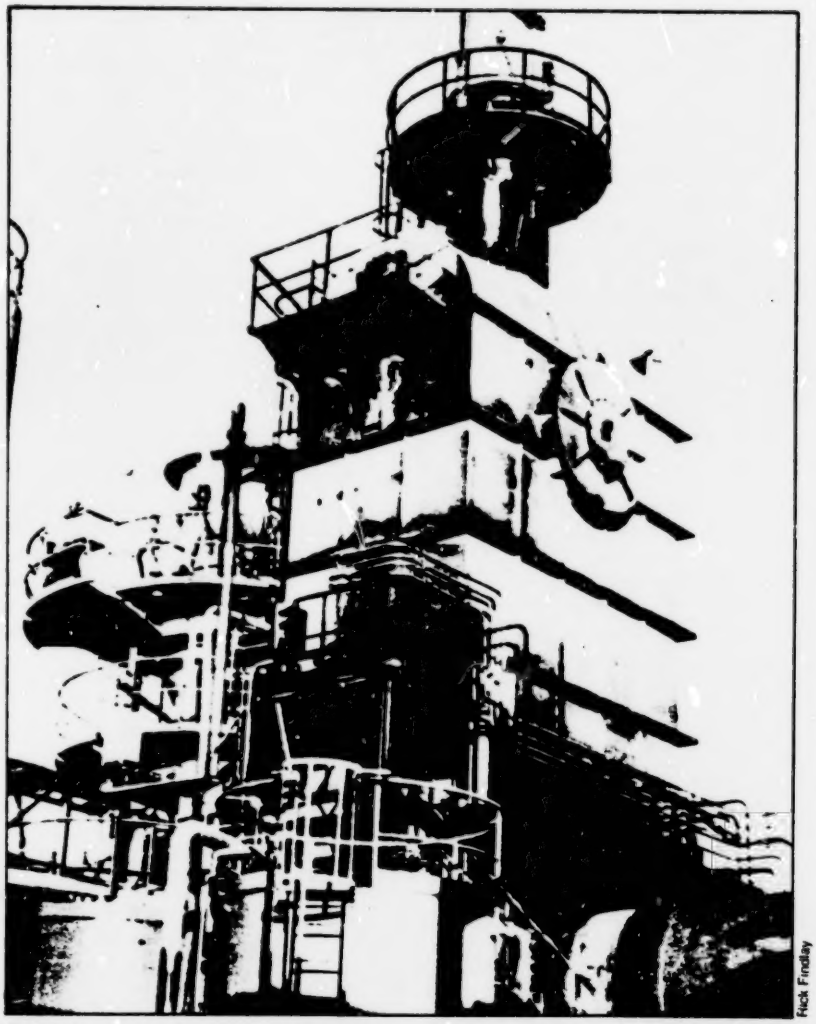
A rotary kiln at the Ebenhausen waste disposal facility in Germany.



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Scrubber system to capture potential air pollutants emitted during incineration of wastes in the rotary kiln.

cyclinder is mounted at an incline so that wastes fed into the high end of the kiln pass through the combustion zone as the kiln rotates. Liquid or solid waste is fed into the kiln via a sealed feed system. The slow rotation of the kiln causes solid wastes to tumble and break apart, thereby improving combustion efficiency.

Ash and non-combustible residues are moved along the cylinder and removed from an ash box at the low end of the cylinder.

Residence time for wastes ranges from seconds for gases to hours for solids, and combustion temperatures range up to 3000°F. In addition to the primary chamber, a secondary combustion chamber is normally used to provide the necessary retention time at controlled exhaust temperatures to ensure that organics are destroyed.[2]

The sizes of existing rotary kilns vary from units that burn a ton of waste per hour to units which burn eight tons of waste per hour. Some rotary kilns are equipped with boilers to reclaim heat energy.[7]

It is common practice to include a stationary after-burner unit after the rotating kiln to ensure complete combustion of the off-gases. Frequently, the after-burner is fueled with rich liquid organic wastes, and combustion occurs at temperatures of 1200°C or higher.[6]

The presence of inorganic contaminants and halogens in the wastestream necessitates the use of emission control devices such as scrubbers and electrostatic precipitators to remove metal oxides and halogens such as chlorine present in the exhaust gases of the after-burner.

Fluidized Bed

Application

Fluidized bed incinerators are well suited to burn certain kinds of sludge. At present, they are used primarily to dispose sludges from municipal wastewater treatment plants, oil refineries, and pulp and paper mills. Fluidized bed units cannot be considered for incineration of "as-received" drummed organics because fluidized bed incinerators typically operate at much lower temperatures than rotary kilns or liquid injection incinerators, and hence are limited in the types of organic wastes that they can safely destroy.

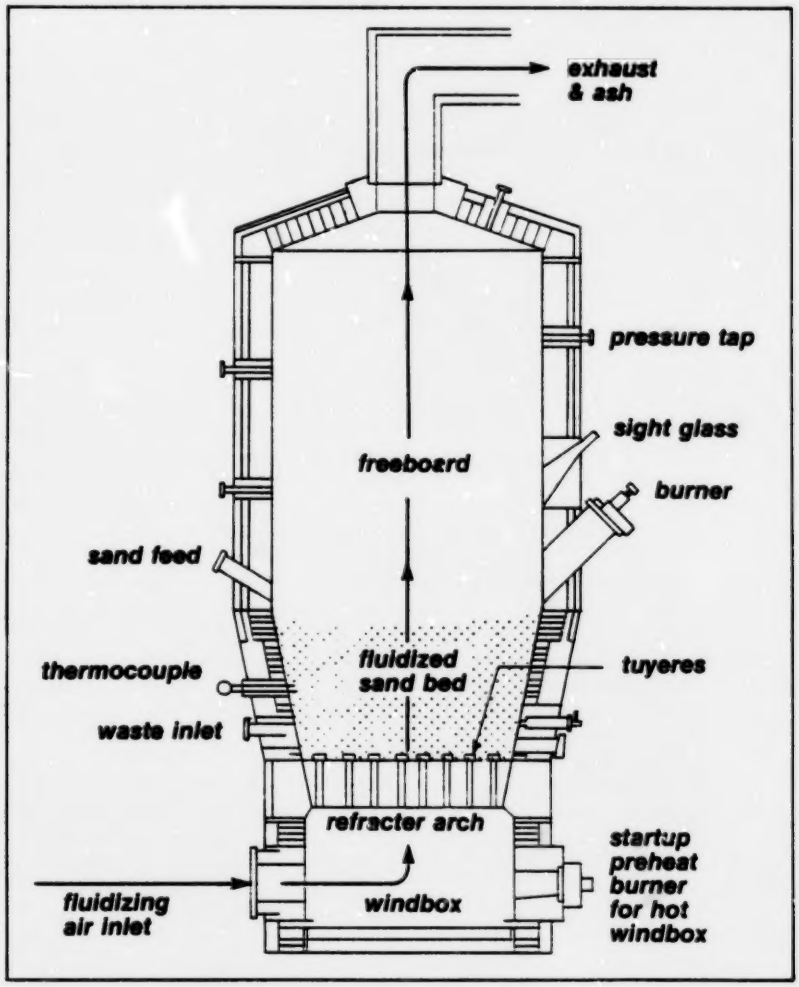
Some industries report burning organic wastes from pharmaceutical manufacturers, phenolic wastes, methyl methacrylate, old munitions, spent blasting abrasives containing organotin compounds, and an organic dye water slurry.[11] Fluidized bed combustion studies on chlorinated hydrocarbons (mainly polyvinyl chloride) have shown that chlorine can be neutralized by using a substance such as dolomite for the bed material.[12] In such instances, the dolomite bed acts as a catalyst to assist in the destruction of the chlorinated hydrocarbon, as well as trapping free chlorine from the destruction of the molecule. In general, however, there is only limited data on the use of fluidized beds as hazardous waste incinerators.

Examples of fluidized bed installations in existence for indust-

Figure 4
Fluidized Bed Furnace

Wastes are injected into the sand bed where combustion occurs within the fluidized medium. The sand is fluidized by forcing combustion air through a perforated plate under the sand.

Source: Hazardous Wastes in Northern and Western Canada, Vol. 2, prepared for Environment Canada, December 1980



rial waste sludges include Papier Cascades Inc. (Cabano, Quebec) and two Amoco installations, one in Mandan, North Dakota and one in Maynard, Massachusetts. Other applications include the incineration of waste sludges from distilleries, packing houses and pulp and paper processes.

Process Description

The fluidized bed incinerator is a vertical, refractory-lined, cylindrical vessel which contains a bed of inert granular material such as sand. The sand is fluidized by forcing combustion air through a perforated metal plate under the sand. The upward flow of air through the sand bed results in a dense turbulent mass which behaves much like a fluid.

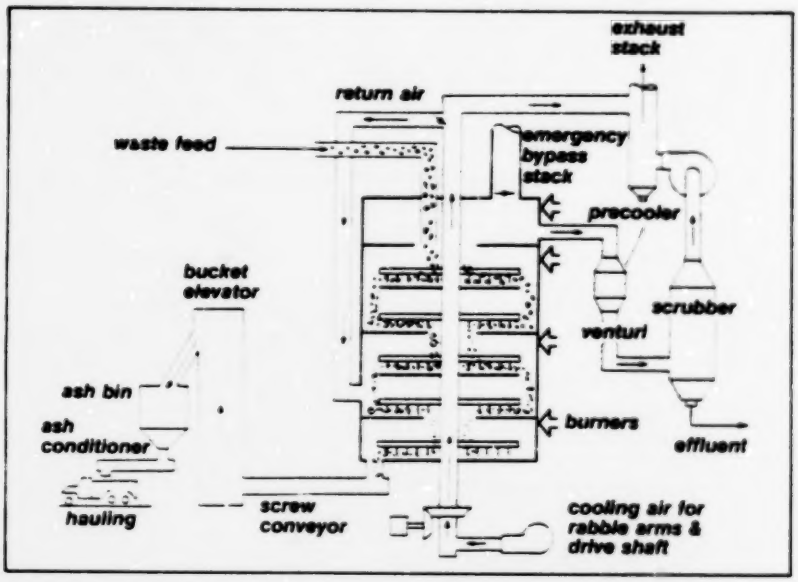
The wastes are injected into the bed where combustion occurs within the fluidized medium. Sand bed temperatures typically range from 750 to 870°C, and the bed acts as a large heat reservoir.[6] The heat capacity of suspended sand is several times greater than that of a gaseous stream at the same temperature. Heat is transferred from the sand to the waste. As the waste is incinerated, the exothermic heat of combustion is transferred back into the bed. Since the mass of the heated turbulent bed is much greater than the mass of the waste, heat is transferred rapidly to the waste material and destruction of the waste occurs in a few seconds.

The exhaust gases move up into the freeboard zone (see Figure 4), which functions at a lower velocity, allowing suspended particles to return to the bed and providing additional retention time for complete combustion.[2] The lower velocity freeboard zone also ensures that sand particles are not carried over with the exhaust gases. Ash from the incineration process is reduced in size by the bed motion and eventually is carried out of the combustion chamber with the exhaust gases.

Figure 5
Multiple Hearth Furnace

Rotating rabble arms and teeth push the wastes across the hearths to drop through holes. The waste cascades down to increasingly hotter hearths for burning.

Source: Hazardous Wastes in Northern and Western Canada, Vol. 2, prepared for Environment Canada, December 1980



Multiple Hearth Incineration

Application

Multiple hearth incinerators are used to incinerate municipal sewage sludge. Because the operating temperature of multiple hearth incinerators tends to be much lower than those of rotary kilns and liquid injection incinerators, multiple hearth units are limited in the types of hazardous wastes that they can destroy. Some industries are currently using multiple hearth incinerators to burn tar and certain types of chemical sludge. These incinerators are also used to regenerate activated carbon systems and in ore roasting operations.

Process Description

A multiple hearth incinerator consists of a refractory-lined, circular, steel shell with multiple refractory hearths located one above the other[6] (see Figure 5). Sludge and other solid waste enters the incinerator at the top through a feed point. Rotating rabble arms and teeth push the wastes across the hearths to drop through holes. The waste cascades down to increasingly hotter hearths for further burning. Frequently, waste greases, tars and combustible liquid organics are injected through side ports to enhance combustion.

Calcination

Application

Calciners can be of various types including open hearth calciners, rotary kiln calciners and fluidized bed calciners. Calcination technology is commonly used in the production of cement, lime, magnesia, plaster, and in the smelting of sulphide and carbonate ores. Calcination technology lends itself to chemical recovery from hazardous wastes, such as mercury recovery from the roasting of mercury sludges.[7]

Process Description

Calcination is an energy-

intensive, endothermic process used to recover metals and other non-combustible materials from waste sludges. Heat is applied to the sludge to drive off volatile and thermally decomposable inorganic components. The burning process results in a dry powdered or sintered solid product suitable for materials recovery, further processing or disposal.[7]

Calcination occurs typically at temperatures of 1000°C. Because the calcination process releases particulates in the exhaust gas stream, it is necessary to install emission control devices such as wet scrubbers, filters, cyclones, electrostatic precipitators or gas absorption equipment for proper control.

Molten Salt Incineration

Application

Molten salt incineration is an emerging technology that offers great promise in destroying some of industry's most hazardous organic wastes. The technology has proven itself in destroying waste pesticides and pesticide containers. Perhaps the most attractive feature of molten salt technology is that small-scale incinerators could be constructed as portable units that can be hauled to the source of the waste.

The molten salt destruction process was developed by Rockwell International (Canoga Park, California). Pilot scale facilities exist in Idaho and Santa Susana, California.[13]

Anti-Pollution Systems (APS) has developed an alternative molten salt process designed for easier removal of ash and to avoid problems when water is introduced directly into the melt. APS has designed a portable molten salt unit that can be fueled with propane. This system has been used to combust tannery wastes so that chromium metal can be recovered. The unit also scrubbed hydrogen chloride and raw halogens generated from the combustion of aluminum chlorohydrate.[11] In another application of the APS process, textile manufacturing wastes containing acrylic residue are purified in a melt consisting of potassium and calcium nitrates.[11]

Process Description

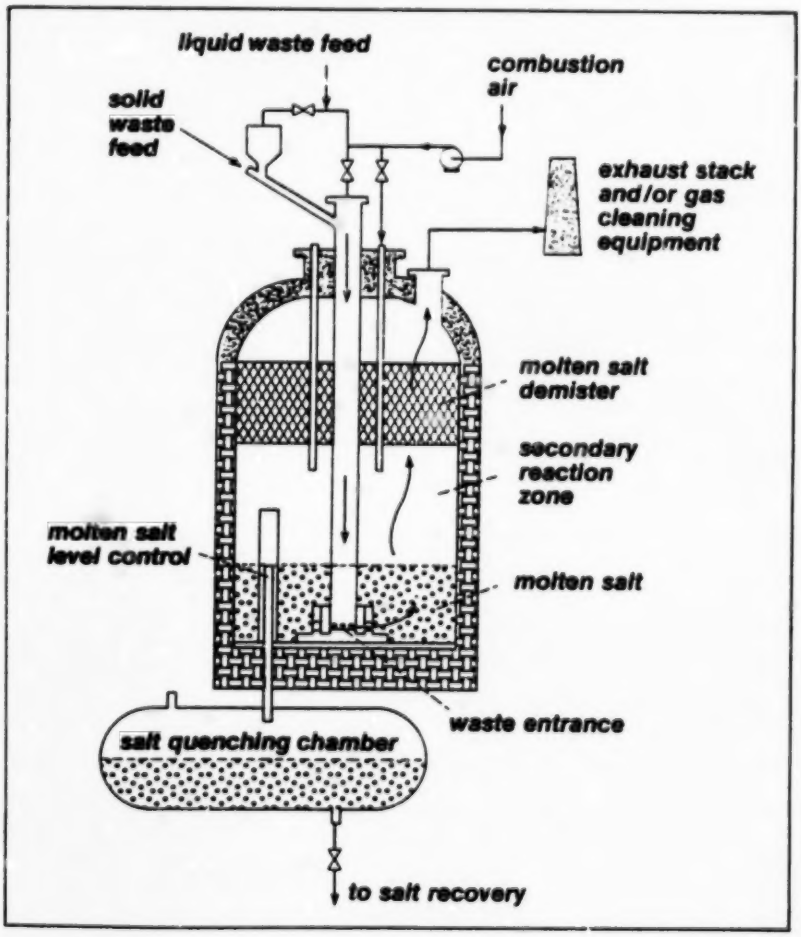
Molten salt incineration is a relatively new method of destroying hazardous organic wastes which simultaneously scrubs halogens and other objectionable byproducts from the exhaust gases. Molten salts act as catalysts to permit complete combustion at temperatures below those of normal combustion.[14] For example, salt bath temperatures of 800° to 1000°C are adequate to destroy PCBs using molten salt technology. In contrast, conventional high-temperature incinerators require a temperature of 1200°C to destroy PCB wastes.[15]

Molten salt incineration is based on the injection of a mixture of waste material and air under the surface of a pool of molten sodium carbonate or other salt (see Figure 6). The hydrocarbons of the organic waste are immediately oxidized to carbon dioxide and water, and the combustion byproducts containing such elements as phosphorus, sulphur, arsenic and the halogens react with sodium carbonate. These byproducts are retained in the melt as inorganic salts rather than released to the atmosphere as volatile gases.[16]

Various types of salts can be used. "Neutral" salts include the metal halide salts. "Oxidative" salts donate oxygen while taking up hydroxides, oxide, chlorate,

Figure 6
Molten Salt Incinerator

Source: *Hazardous Wastes in Northern and Western Canada*, Vol. 2, prepared for Environment Canada, December 1980



sulphate and nitrate byproducts.[5]

Any gaseous products that escape from the molten salt layer during the combustion of wastes are burned in the secondary reaction zone above the melt to complete the oxidation of combustible material. Combustion gases then pass through a de-mister which traps particulates in the off-gas stream for return to the salt bath.

As the inorganic products resulting from the reaction of organic halogens, phosphorus, sulphur and other compounds build up in the molten bed, it becomes necessary to regenerate or replace the molten salt.[17] Waste molten salt can be reacted with lime in an aqueous or molten medium to form a water-insoluble calcium salt residue.

Plasma Arc Torch

Application

Plasma arc technology is suitable for the destruction of both solid and liquid wastes. Liquid wastes can be pumped continuously into the plasma arc reaction vessel (see Figure 7). Solid wastes are first shredded and then deposited in the reaction vessel where they fall into the molten slag pool at the bottom. Excess slag is removed from the reaction vessel as necessary.

Resource Recovery Corporation (Raleigh, North Carolina) holds the patent rights to the plasma torch.[6] The Canadian subsidiary is the Canadian Resource Recovery Corporation (Montreal, Quebec). Although not in widespread use yet, several plasma arc units have been built and successfully operated in the destruction of liquid industrial wastes such as toluene and PCBs.[6] The capital cost for a plasma arc system that processes 16.5 cubic metres of waste per day is estimated at $500,000. Electrical energy costs are calculated at $20 per tonne of waste destroyed.[6]

Both American and Canadian governments are supporting further development of plasma arc technology as a means of hazardous waste disposal. Environment Canada, Ontario Hydro and the Ontario Ministry of the Environment are providing the Royal Military College (Kingston, Ontario) with financial assistance in the preparation of commercially available plasma arc systems that destroy PCBs.[18]

There are many reasons for optimism regarding this emerging disposal technology. The plasma arc system is relatively versatile in that it can handle both solid and liquid wastes.

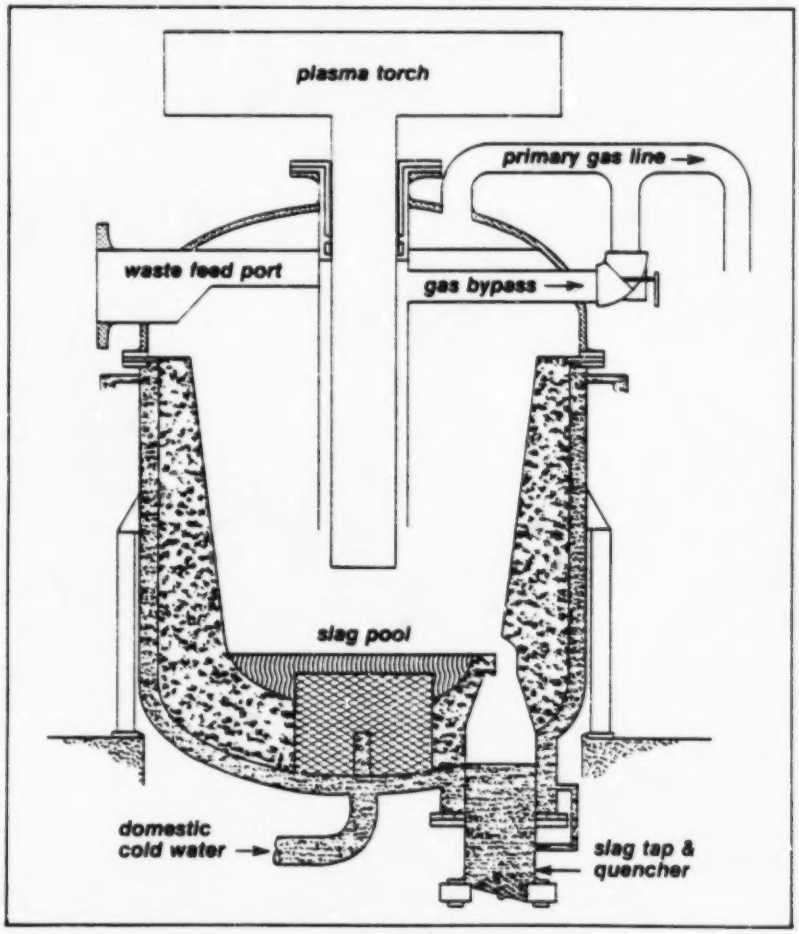
Unlike incineration in the presence of oxygen, plasma arc pyrolysis generates a much smaller volume of gaseous end products than incineration. Only a small amount of gas is required to generate the arc, and the majority of carbon in the feedstock can be converted to carbon black.[10] The reduced volume of exhaust gases from plasma arc pyrolysis reduces the size requirements for downstream gas clean-up devices. Hence process equipment can be relatively compact.

The most promising aspect of plasma arc technology is that it is suitable to both portable and small-scale installations. In the future, many of the larger companies might invest in on-site destruction units. The smaller businesses may be serviced by a travelling plasma arc unit.

Figure 7
Plasma Arc Reaction Vessel

Waste materials and air are injected under the surface of a pool of molten sodium carbonate, resulting in the immediate oxidation of the waste.

Source: Hazardous Wastes in Northern and Western Canada, Vol. 2, prepared for Environment Canada, December 1980



Process Description

Plasma torch technology grew out of the United States space programme. NASA scientists required a very intense heat source in their simulation experiments on the ability of heat shields to protect space vehicles upon re-entry into the earth's atmosphere. Plasma arc technology was developed for this purpose.[19]

A plasma arc torch functions to pyrolyze wastes into combustible gases by exposure to a gas which has been energized to its plasma state. A plasma is a gas consisting of charged and neutral particles, having an overall charge of zero, and exhibiting collective behaviour.[10] Plasma is characterized by a good ability to conduct electricity.

An electrical current is passed through a low pressure gas which activates the gas molecules into ionized atomic states. Plasma gas temperatures of about 50,000°K are achievable. As waste materials are fed into the plasma zone, the injected waste materials absorb energy radiated by the ionized gas molecules. This process occurs in the absence of oxygen.

The transfer of energy from the decaying plasma species to the molecules of waste material causes the breakdown of the wastes into atom and ion constituents. Plasma arc pyrolysis is based on molecular fracture rather than on chemical oxidation typical of incineration.[10]

Although plasma arc technology has been known for some years, commercializing the technology has taken a long time. The extreme heat generated by the plasma torch caused the plasma torch to destroy itself within minutes. Ongoing research has resulted in the construction of plasma arc torches that no longer destroy themselves and require relatively little maintenance.

Wet Air Oxidation

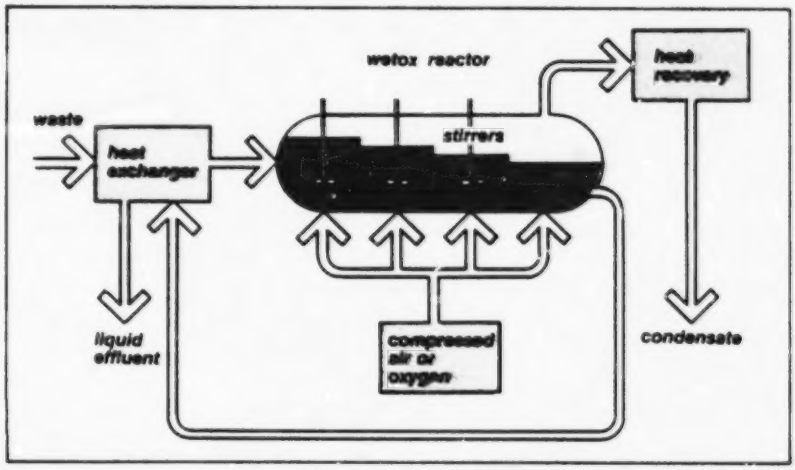
Application

Wet air oxidation technology is applicable to aqueous organic wastestreams containing approximately 1 to 20% organic material such as spent pulping liquor from the pulp and paper industry, paint sludges, food wastes and refinery sludges.

Figure 8
Wetox Process

The wastestream is pumped into a multi-compartment reactor designed to agitate and aerate the waste. Reactor temperature ranges from 200° to 300°C and reactor pressure is equivalent to 40 atmospheres.

Source: Hazardous Wastes in Northern and Western Canada, Vol. 2, prepared for Environment Canada, December 1980



Process Description

Wet air oxidation achieves oxidation of water-borne organic wastes without prior dewatering. The normal oxidation process is accelerated by subjecting wastes to increased temperatures and pressures within a reaction vessel.[20]

The wastestream is pumped into a multi-compartment reactor designed to agitate and aerate the waste (see Figure 8). Reactor temperature ranges from 200 to 300°C[21] and reactor pressure is equivalent to 40 atmospheres.[6]

Typically, wet air oxidation achieves reductions in organic material in the wastestream of 75 to 90% as measured in terms of chemical oxygen demand (COD). It has achieved 99.9% and higher destruction of specific contaminants such as phenols, diphenylamine and pentachlorophenol. These materials are broken down to simpler molecules which are further oxidized.

Wet air oxidation works well in combination with a biological treatment system. Wet air oxidation breaks down toxic organics to simpler low molecular weight species. The biological system treats the effluent to destroy these compounds to a level at which the treated wastestream may be discharged.[22]

A major problem faced by biological systems is the disposal of sludge produced during wastewater treatment. The sludge resulting from biological treatment can be readily oxidized in the wet air oxidation process. Thus the two processes are symbiotic, each destroying what the other cannot. Figure 9 shows how the two processes might work in a situation when both concentrated and dilute organic wastestreams are generated.

Research into wet air oxidation techniques to destroy aqueous wastes is occurring at the Ontario Research Foundation (Mississauga, Ontario). The specific process under investigation at the Ontario Research Foundation is known as the Wetox™ process. Wetcom Engineering (Scarborough, Ontario) possesses the rights to market Wetox™ technology.

The Wetox™ process can be applied to the destruction of not easily biodegradable materials such as pesticides or substances that may create an air pollution hazard when incinerated in a conventional manner.[23] While the system destroys organic wastes, it can recover inorganic materials that can be recycled or removed for disposal. The process allows for the recovery of resources such as nitrogen converted to ammonia and sulphur converted to sulfuric acid. In addition to materials recovery, up to 60% of the potential energy in the incoming waste can be recovered from the oxidation of more concentrated wastes (generally for those wastestreams containing more than 5% organics).[18]

Cement Kilns

Application

At present, non-halogenated organics such as certain waste solvents and still bottoms from reclaiming operations are purchased routinely by some cement companies for use as a fuel supplement in the operation of rotary kilns.

There is interest in Canada, Sweden and the United States in destroying hazardous halogenated wastes such as PCBs in cement kilns. Test burns in these countries showed PCB destruction efficiencies exceeding 99.99%.

Process Description

In the production of cement, limestone is subjected to very high temperatures, hovering at 2600°F for several hours in a large rotary kiln. The solid material which results from the heating process is ground up and becomes the major constituent of cement.

One advantage of the cement kiln is the tremendous thermal inertia of the kiln and its contents. Even if the burner goes out, the kiln will remain at very high temperatures for minutes, even hours, allowing ample time to turn off the waste injectors.

Proponents of waste incineration in cement kilns suggest that incineration temperatures are guaranteed to remain optimal and hence ensure virtually complete destruction of wastes. Failure to do so would interfere with the production of high quality cement.

Another advantage of burning chlorinated hydrocarbons in a cement kiln is that the alkalinity of the cement neutralizes the hydrochloric acid produced during the destruction of PCBs. Despite the obvious economic advantages of using an existing cement kiln to incinerate hazardous wastes, there are several drawbacks to this disposal option.

As with other centralized treatment facilities, the transportation of hazardous wastes to an incineration site entails the risk of spill and environmental mishap. When siting new waste treatment facilities, there is greater flexibility in locating such a facility remote from population centres. When using an existing cement facility, no such flexibility exists.

If cement kilns are remote from populated areas, and if the facility is upgraded specifically to handle wastes and capture air pollutants, the use of existing cement factories to incinerate wastes may be a cost-effective option for the disposal of hazardous wastes compared to building a new incinerator.

At-Sea Incineration

Application

Typical wastes incinerated at sea include pesticides and other halogenated organics.

At present there are two functioning incinerator ships. The Vulcanus, previously operated by Ocean Combustion Service BV, a Dutch subsidiary of the Hansa Shipping Line (Bremen, West Germany)[24], was sold to Waste Management Incorporated (Chicago, Illinois) in the latter part of 1980.[2] The Vulcanus, now equipped with a high temperature incinerator, is a former freighter whose waste storage tanks have a capacity of 770,000 Imperial gallons.

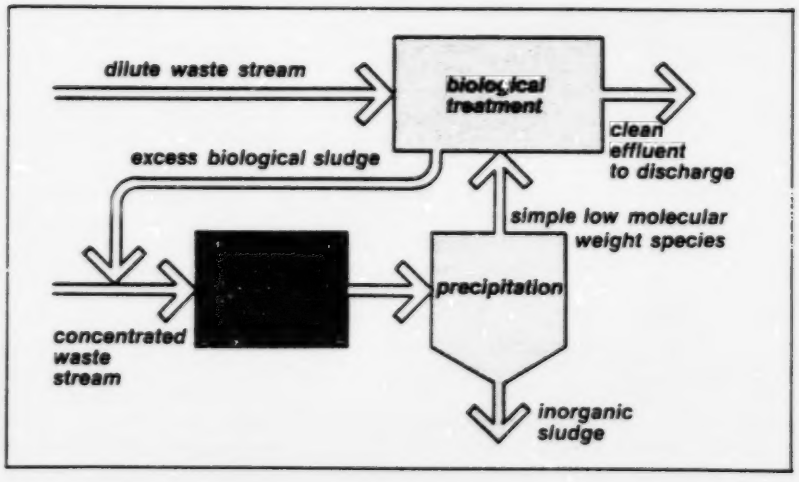
The Vulcanus specializes in the burning of halogenated organics. Its incinerator system can handle

Figure 9

Use of Biological Treatment and Wet Air Oxidation to Treat Both Dilute and Concentrated Organic Wastestreams

Wet air oxidation breaks down toxic organics to simpler low-molecular-weight species. The biological system treats the effluent to destroy these compounds to a level at which the treated wastestreams may be discharged.

Source: W. R. Laughlin, Ontario Research Foundation, 1981.



waste with a chlorine content as high as 70%. In 1977, the United States Environmental Protection Agency gave permission to have the Vulcanus burn more than 10,000 tons of surplus Agent Orange.[24] Agent Orange, a toxic herbicide contaminated with dioxins, was used as a defoliant during the Viet Nam war. Waste destruction efficiency of Agent Orange was reported to be 99.9%.[2]

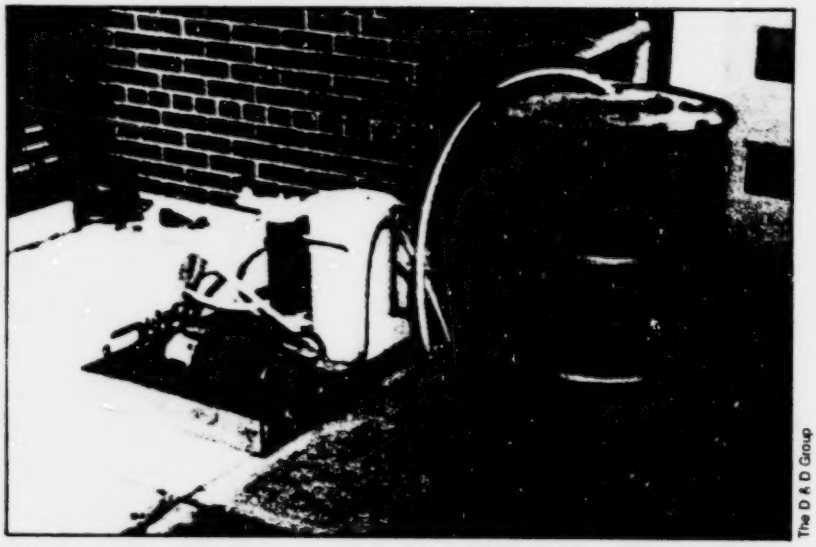
The Mathias II is an incinerator ship owned and operated by Industrie Anlage (Berlin, West Germany).[24] Hazardous wastes are collected from several European countries for storage in Antwerp (Belgium). Wastes are then transferred to the Mathias II and incinerated in the North Sea. Mathias I, a prototype for Mathias II has been sold and no longer operates as an incinerator ship. A sister ship, Mathias III has been taken out of service for repairs.

Late in 1980, the Environmental Protection Agency and the Maritime Administration announced plans to push for the construction of a fleet of waste incineration ships to serve the North American waste market.[25] Financial assistance and loan guarantees are being considered to fund privately-owned American incineration ships. In the absence of private sector interest, the United States government itself may oversee construction of a prototype incineration ship.[25]

Process Description

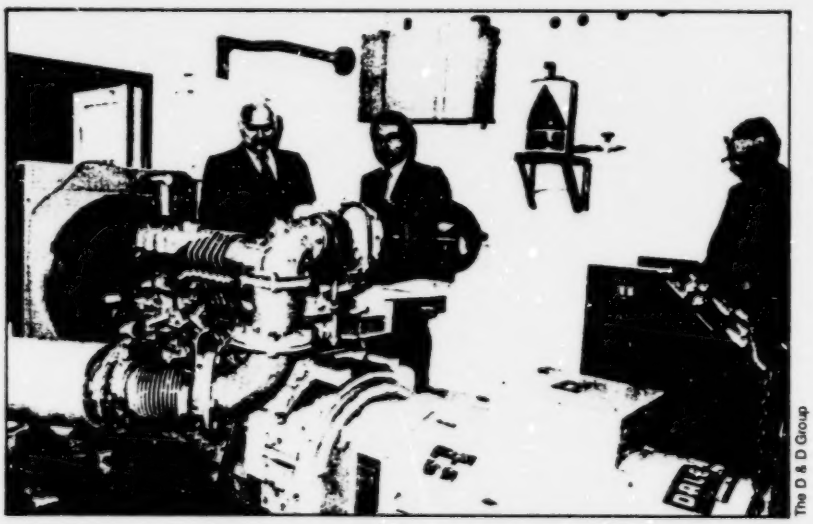
The incineration of hazardous organic wastes on ships situated in the ocean has occurred since the early 1970s. Incinerator ships are ocean-going vessels that are equipped with a high temperature incinerator, such as a liquid injection unit.

The stimulus to burn hazardous wastes at sea has been two-fold. First, incinerating wastes at sea is much cheaper than burning these wastes on land. In 1979, at-sea incineration cost under $100 (U.S.) whereas the incineration of equivalent organics on land cost several hundred dollars.[24] The reason for the reduced operating cost of at-sea incineration compared to land incineration is the absence of pollution abatement equipment on ship incineration systems. Secondly, by burning wastes in the ocean, waste disposers are able to circumvent public opposition typical when siting incineration facilities on land.



The D & D Group

D & D's portable filtration unit used to pump PCB fluids from transformers into a container.



The D & D Group

D & D's PCB destruction unit which is based on the design of a diesel engine.

Mobile PCB Destruction

Process Description

The D&D Group (Smithville, Ontario) has developed a mobile PCB destruction unit based on the design of a diesel engine. Preliminary testing by the Ontario Research Foundation and Environment Canada in 1980 indicated a high PCB destruction efficiency.

If the unit is licensed for use in Canada, the D&D Group will be able to provide a complete on-site detoxification service. PCB-containing fluids are first drained from electrical transformers and hydraulic equipment. A solvent is used to flush and decontaminate the equipment. After cleaning, functionally sound equipment is

refilled with a less hazardous substitute fluid.

Distillation methods are used to separate the solvent trichlorobenzene from the PCB mixture. Trichlorobenzene is recovered and re-used to flush and decontaminate PCB-containing equipment.[26] The final step in the PCB detoxification service is the destruction of PCBs in the mobile destruction unit.

4. Radiation Destruction

Most waste destruction technologies based on radiation are new technologies or novel variations of established technologies.

Radiation destruction technologies depend on the energy of electron beam, ultraviolet (UV) or other radiation to provide the energy necessary to break apart molecular bonds in the hazardous material. The absorption of radiation at certain wavelengths causes the waste chemical compound to decompose or break down. In some cases, the incoming radiation functions as a catalyst to accelerate an otherwise chemical destruction of the waste.

Types of highly hazardous chemicals under scrutiny for destruction by radiation include dioxins, PCBs, pesticides, chemical warfare agents, explosives and propellants. One of the major advantages of radiation destruction systems is the energy efficiency of the waste treatment process, particularly in comparison to many of the incineration techniques.

Radiation destruction technologies described include:

- Photolysis
- Electron radiation
- Dehalogenation
- UV-assisted chlorinolysis

Photolysis of Dioxin

Dioxin is known to break down in the presence of UV light. As with any emerging waste disposal technology, the issue remains whether the degree of destruction is adequate.

In 1980, Syntex Agribusiness Inc. (Springfield, Missouri) employed a specially designed extraction photolysis process to destroy 13 pounds of dioxin contaminating 4300 gallons of sludge.[27]

The dioxin-laden sludge discovered on Syntex's premises had been abandoned by a former pharmaceutical company manufacturing a hexachlorophene skin cleanser. The distillation residue resulting from the synthesis of hexachlorophene contained more than 300 ppm of dioxin.

I.T. Enviroscience (Knoxville, Tennessee) had designed a treatment process to destroy dioxin contaminants in sludge. In this process, the dioxin is extracted from the sludge using a common organic solvent. The extract is then exposed to ultraviolet light which breaks down the dioxin compound. The solvent is distilled for recycling within the process[27] (see Figure 10). The dioxin level in the residue was reduced from 343 ppm to less than 0.5 ppm. The 1980 cost to Syntex for the equipment and installation was $500,000 (U.S.).

Electron Radiation

Research at the Michigan Institute of Technology has revealed that electron beam radiation is highly effective in destroying water-dissolved PCBs and other toxic chemicals. The electron beam technology was not successful, however, in destroying PCBs in wastestreams high in lipid content. In pure water, a 10-kilorad dose produced almost complete PCB destruction. As the concentration of lipid increased in the wastewater, the effectiveness of the treatment was severely inhibited.[11]

Electron radiation of the persistent, urea-type pesticide known as Monuron resulted in almost complete destruction after exposure to 30 kilorads of radiation.[28]

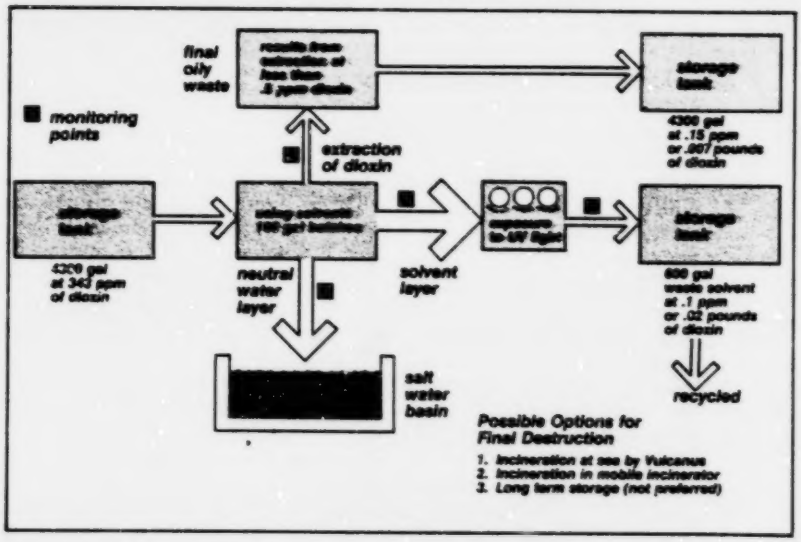
Dehalogenation by UV Radiation

The Atlantic Research Corporation has developed a process for breaking carbon and halogen bonds in wastes.[11] Waste halogenated organics are dissolved in

Figure 10
Photolysis of Dioxin

Using the extraction photolysis process, 4300 gallons of sludge contaminated by 13 pounds of dioxin (343 parts per million) were detoxified to a dioxin level of less than 0.5 parts per million — a reduction of over 99%.

Source: "Destroying Dioxin: A Unique Approach," Waste Age, October 1980.


final oily waste
monitoring points
extraction of dioxin
storage tank
4300 gal at .15 ppm or .007 pounds of dioxin
4300 gal at 343 ppm of dioxin
neutral water layer
solvent layer
600 gal waste solvent at .1 ppm or .02 pounds of dioxin
recycled
salt water basin
Possible Options for Final Destruction
1. Incineration at sea by Vulcanus
2. Incineration in mobile incinerator
3. Long term storage (not preferred)

methanol and exposed to UV radiation and hydrogen. Cleavage of the carbon-halogen bonds results in the formation of free halogen ions. Research to date indicates that dehalogenation via UV radiation is applicable to kepone, PCBs, and tetrabromophthalic anhydride.[11]

UV-Assisted Chlorinolysis

Chlorinolysis refers to the destruction of hazardous wastes by exposure to chlorine at high pressure and low temperature, or at high temperature and low pressure. Depending on the constituents in the wastestream, chlorinolysis may result in the undesirable formation of hazardous reaction products such as carbon tetrachloride, carbonyl chloride and hydrogen chloride.[29]

Chlorinolysis in combination with UV exposure is observed to minimize the production of hazardous byproducts. Chlorinolysis catalyzed by UV light has been used to treat dilute concentrations of hydrazine in wastewater. No undesirable products were found in the wastewater at the end of the treatment process. Significant amounts of chlorinated contaminants remained in wastewater when processed by chlorinolysis without UV radiation.[11]

5. Land Disposal

In recent years, the waste disposal industry has developed and made available better-designed methods of isolating and storing industrial wastes. The strategy is to encase the toxic material to prevent it from escaping into the environment.

It must be stressed, however, that there is an enormous difference between using land disposal to dispose of residuals such as ash, and using them as a primary disposal method. The difference is one of volume and waste type. If only the residuals are solidified and landfilled, the volume of wastes buried would be a small fraction of the total wastes treated. If solidification is used as a primary disposal method, this may result in the majority of the industrial wastes being put underground.

Waste encapsulation and solidification processes are still in the development stage. They have received only limited testing as to the full range of chemical and climatic interactions possible that could contribute to the movement of toxics from the containment site.

No single technology such as solidification or secure landfill can adequately manage all industrial wastes. Industrial wastestreams are composed of thousands of constituents, each with its own set of physical and chemical properties.

Some of the constituents will react with others. Some will degrade the containment structure over time. Carefully controlled lab experiments suggest that engineers can do much to ameliorate the destructive actions of the various wastestreams by keeping wastestreams separate, or by mixing in special additives.

Transferring carefully controlled lab experiments to a land disposal facility is another matter. Human error in analyzing wastestreams or in keeping certain constituents separate may result in accelerated leakage from the containment area. Given the lack of evidence on the long-term effectiveness of such technologies as solidification, the preferred management route is to exhaust all other waste treatment methods before resorting to land disposal.

Four developments in land disposal technology include:

- Solidification
- Secure landfill
- Deep-well disposal
- Retreivable storage

Solidification

Solidification is the fixation or encapsulation of waste to produce a solid end product. Fixation is based on the addition of an agent such as lime or cement to turn the waste into a concrete-like solid. Encapsulation is a physical process in which the solidification agent surrounds the waste particles and makes them adhere together into a mass. The main objective of solidification is to chemically and physically trap toxic constituents within the solid. Leaching of some constituents may still occur, but at a significantly reduced rate.[30] Solidification technology was developed for use in those instances where secure landfill was not available.

Solidification is an outgrowth of processes developed to manage low-level radioactive wastes. The

Table 6

Suitability of Wastes for Solidification

Solidification	Wastes Suitable for Solidification	Wastes Detrimental to Solidification
Cement-based	Toxic inorganics Scrubber ash and sludges	Organics Some anions
Pozzolanic	Toxic inorganics Scrubber ash and sludges	Organics Some anions
Thermoplastic	Toxic inorganics	Strong oxidizers
Organic Polymer	Toxic inorganics	Acidic materials Strong oxidizers
Encapsulation	Toxic and soluble inorganics	Strong oxidizers

Source: *Toxic and Hazardous Waste Disposal*. Volume I and II Ann Arbor Science.

most common solidification techniques include the following:

Cement-based
Lime-based (pozzolanic)
Thermoplastic
Organic polymer
Encapsulation

Solidification processes are compared in Table 6 with respect to the types of wastestreams suitable and unsuitable to particular solidification agents.

Cement-Based

Cement-based solidification processes use Portland cement and other additives such as fly ash and silicates to solidify inorganic wastes and sludges rich in metals. The high pH of the cement mixture tends to keep the metal ions in the form of insoluble hydroxide or carbonate salts.[31]

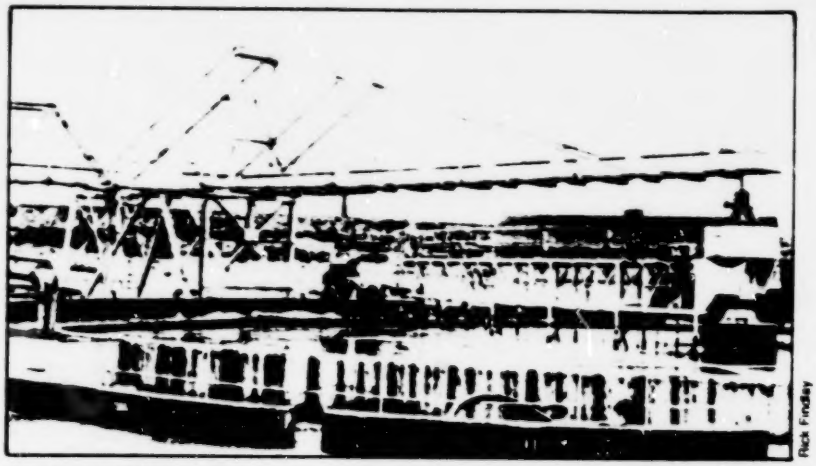
Common cement consists of calcium silicates and calcium aluminate which incorporate the waste into a rock-like mass during solidification.

Organics and some anions are not compatible with the cementing process and generally weaken the cement. Soluble ions such as chlorides, sulfates, sodium and potassium leach relatively easily from the solidified waste.

One factor contributing to the disintegration of the solid is seasonal wet-dry, freeze-thaw cycles, particularly for solidification products occurring above the frost line.[32] The cement-based techniques are the most common of the solidification methods because they are generally the cheapest and easiest to use.[32] Major cement-based processes include the Terra-Tite, Petrifix, Terracrete and Sealosafe processes.

Lime-Based (Pozzolanic)

The term "pozzolanic" comes from Pozzuoli, a city near Naples where volcanic silico-aluminate calcium ash has been mined since before the time of Christ.[32] Lime is mixed with siliceous material and water to produce a very hard material known as pozzolanic concrete. Common additives are cement kiln dust and fly ash from

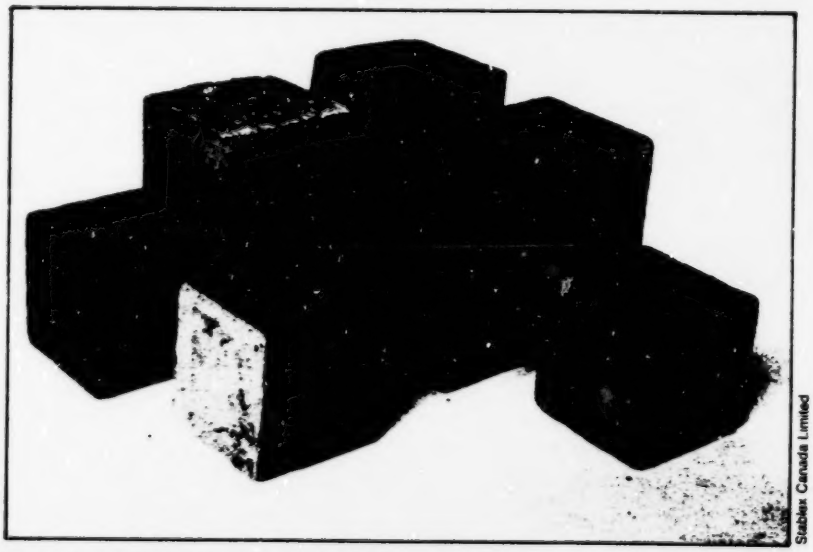


Rick Findlay

During solidification of wastes, the incoming wastestream is mixed thoroughly with the solidification agents in large tanks.

Rick Findlay

Disposal of liquid stabilized product on the ground at a Stablex facility in England.



Stablex Canada Limited

Concrete-like blocks cast from Stablex product.

electric power plants, which are wastes in themselves.[6] Other additives are added if necessary to enhance the strength or impermeability of the solid.

Pozzolanic processes have been used to solidify sludges generated during sulphur scrubbing operations at coal-fired power plants.

IU Conversion Systems (Horsham, Pennsylvania) markets a process called Poz-o-Tec that converts flue gas sludge into a stable material that can be used in properly designed landfills, embankments, roads and parking lots.[32]

Solidified fly ash wastes from coal-burning power plants now underlie the Veteran's Stadium complex in Pittsburgh and some of the runways at Dalles International Airport near Washington, D.C.[33] Fly ash wastes resulting from the burning of coal are considered appropriate for use in construction projects because they are relatively low in heavy metal contaminants. Because sludges from the electroplating industry are very high in metal contaminants, this process is not appropriate for use in road construction.

The Dravo Lime Company (Pittsburgh, Pennsylvannia) markets an additive known as Calcilox capable of solidifying flue gas sludges resulting from the combustion of coal.

Pozzolanic solidification suffers from similar disadvantages as cement-based techniques. Contamination with organic matter may result in organic decomposition after curing, resulting in increased permeability and reduced sheer strength. The solidified wastes are vulnerable to weathering from rain and ice if the resultant solids are not properly capped with clay in a secure landfill. Neither the cement-based nor the lime-based solidification products are completely impermeable to water.

Thermoplastic

Thermoplastic solidification makes use of materials such as polyethylene, paraffin, bitumen or asphalt to bind wastes into a uniform mass.

Unlike cement-based and lime-based solidification, thermoplastic techniques require that the waste be dry before it is mixed with the solidification agent. The solidification agent and wastes are mixed at temperatures ranging from 130 to 230°C in close to equal amounts. Cooling of the mixture results in solidification of the mass.

One advantage of thermoplastic solidification is that the resulting solidified waste is impermeable to water. Contaminant leaching is also lower than for other solidification processes, however, the cost is higher.

The Werner and Pfleiderer Corporation (Waldwick, New Jersey) have used thermoplastic solidification in more than 2000 applications in the chemical, plastics, food and nuclear industries.[32]

Organic solvents capable of dissolving the solidification agent are not appropriate for thermoplastic solidification. Other unsuitable wastes include those containing high concentrations of oxidizing salts such as nitrates, chlorates and perchlorates.[31] Wastes that are volatile at low temperatures present safety problems during the heating of the solidification agent.

Organic Polymer

Organic polymer solidification is based on the addition and thorough mixing of a small amount of monomer to the wastes. A catalyst is added, resulting in the linking of the monomers into a sponge-like polymer.

The sponge-like polymer traps solid waste particles while permitting much of the wastewater to escape. Current research is directed at minimizing the leachate problem.

Several polymer techniques are being investigated. The Teledyne Corporation (Louisville, Kentucky) has developed the urea-formaldehyde process. Washington State University is studying solidification with polyester resins, while the Dow Chemical Company is pursuing the use of polyvinyl chloride as the polymer matrix. Organic polymer techniques are suitable for toxic organics, but not for acidic materials and strong oxidizers.[32]

Other solidification processes suffer from the disadvantage of requiring such large volumes of additives that the resultant product is twice the size or weight of the original waste materials. This contributes significantly to materials and transport costs and landfill sites are filled up twice as fast.

Organic polymer processes require only small amounts of additives to solidify wastes. As little as 3% of the total weight of the final solid may be polymer additives.[32] However, if insufficient resin is used, the matrix will not trap all the wastes.

Other problems exist. The catalysts used in the urea-formaldehyde process are strongly acidic. Many metal ions are soluble in acidic solutions and insoluble in alkaline conditions. Strongly acidic polymerization catalysts redissolve precipitated metal ions, permitting them to leach out in water not trapped in the polymer matrix.[32]

Contamination of the wastes with corrosive materials such as strong oxidizers will result in gradual breakdown of the organic matrix. Both urea-formaldehyde and polyesters are unstable in corrosive environments.[6]

Surface Encapsulation

Surface encapsulation is a process in which wastes are coated with a water-impermeable sealant.

A system developed by TRW Systems (Redondo Beach, California) uses polybutadiene to bind toxic inorganics into small cubes. A thick layer (1 to 2 cm) of high-density polyethylene is fused onto the surface of the cube, encapsulating the waste into a seamless container.

The cost of resin encapsulation is high, partly due to the high costs of petroleum-based resins. As with any hydrocarbon polymer, degradation of the protective plastic coating is accelerated in response to contact with solvents, heat or UV radiation.

Surface encapsulation is a useful technology when applied to the interim storage of waste materials whose recovery is uneconomical at

Rick Findley

Secure landfill at Gallenbach (Germany) showing deposition of incinerator ash and stabilized product.

Rick Findley

Leachate collection well under construction within the secure landfill pit.

Rick Findley

Particularly hazardous chemicals are stored in barrels and placed within a secure concrete vault inside the secure landfill at Gallenbach.

present. Drummed wastes may be encapsulated in their entirety.

TRW Systems are developing a system to encapsulate drums of wastes of unknown composition from abandoned dumpsites. Drums are left sealed and are not analyzed. The drums are placed in a fibreglass cocoon big enough to accommodate warped and dented drums. A layer of high density polyethylene is fused onto the surface and the drums are relocated.[32]

Disposal of Solidification Products

The solidification of inorganic wastes from desulfurization processes that are free of metal contaminants is a reasonable strategy in utilizing scrubber wastes. The solidified product, if free of toxic inclusions, can be used in the construction of roads.

The long-term stability of solidification products rich in metals is currently under debate. Proponents of solidification are seeking approval to place solidified wastes embedded with metals and potentially toxic inorganics in non-secure landfill sites.

Concerns regarding the durability of the stabilized material when exposed to physical and biological factors in the soil have regulators scrutinizing which stabilized wastestreams require secure landfilling.

Secure Landfill

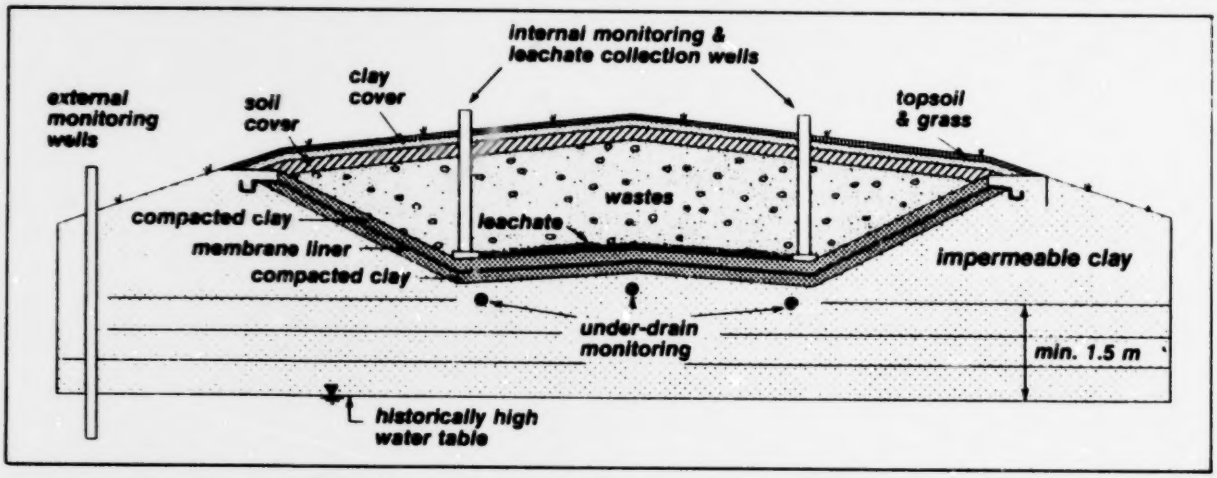
A secure landfill is designed to receive chemical and other industrial wastes. Secure landfills differ from conventional sanitary landfills in the degree to which the site is engineered to diminish the migration of pollutants.

Secure landfill cannot substitute for other waste treatment technologies such as waste reduction, recovery, treatment or destruction. The many environmental problems and unknowns associated with landfill make it a disposal option of last resort, and certainly one whose use should be minimized in the face of more progressive technologies.

Environmental dangers are numerous. Although secure land-

Figure 11
Typical Secure Landfill Cell

The pit is underlain with a leachate collection system that pumps migrating liquids to a leachate treatment system. The pit is lined with a synthetic membrane, clay liner or both.
Source: Need for Waste Management Facilities and Available Technologies: Annex One, prepared for the Ontario Ministry of the Environment, November 1980



fill technology substantially reduces the migration of contaminants compared to previous systems, secure landfill is limited in types of wastes that it can confine.

The common disposal method is to co-dispose industrial wastes with municipal wastes in unlined pits. Depending on the geology of the region, existing landfill sites may be located in a natural clay deposit. However, some existing landfill sites are permeable to leachate movement.

There are many variations in the design of secure landfills. The simplest variation is a pit with a synthetic membrane or clay liner (see Figure 11). In some instances, where natural clay deposits are thick, no synthetic membrane is used.

The pit is underlain with a leachate collection system that pumps liquids to a leachate treatment system. The perimeter of the buffer zone contains a few monitoring wells which collect ground water for analysis of contaminants. Several years may elapse before a secure landfill is full. At closure, a layer of clay is deposited over the wastes to minimize water movement into the pit.

Some of the synthetic polymers used to line the landfill pit are vulnerable to disintegration by specific solvents and corrosive agents.[2] Based on research by the EPA, polypropylene appears to be one of the more versatile synthetic liners for secure landfill. Polyvinyl chloride and polyethylene liners have limited ability to retain acidic pickling waste and electroplating sludge (see Table 7).

Clay is mistakenly identified as a highly impermeable material. This perception is based on the poor ability of water to pass through clay. Water will penetrate clay, but at an exceedingly slow rate because of the nonporous structure of clay.

The permeability of clay is increased dramatically when penetrated by certain organics, acids and bases. Clay liners are dissolved by the infiltration of a chemical that dissolves the surfaces of the pores in the clay. Either organic acids or organic bases may solubilize portions of the clay. Acids have been reported to solubilize aluminum, iron, alkali metals and alkaline earths while bases will dissolve silica.[34] Since clay minerals contain both silica and aluminum in large quantities, they are susceptible to dissolution by acids and bases. The net result is that pore size increases and the clay becomes more permeable.

Clay types differ in how much they swell or shrink when they become wet or dry. Montmorillonite clays undergo extreme swelling or shrinkage, depending on moisture content. Similarly, organic leachates can cause shrinking or swelling of clay liners.

Montmorillonite clays are reported to swell as a result of exposure to several forms of xylene, cyclopentane, alcohols, glycols and ketones.[35] A liner which has swelled and heaved may lose its integrity during heaving, or it may shrink later when water replaces infiltrated organic chemicals.[36] In either situation, the overall ability of the clay layer to stop the movement of contaminants is diminished.

Another factor that increases the movement of leachate through clay is the ability of certain materials such as sulphates to deflocculate clay. Clay resists the movement of water because of the physical structure of the clay. Addition of certain chemicals causes the structure of the clay to change and become more porous.

Secure landfill sites are designed to be the final resting place for the full range of industrial wastes. The mixing of certain wastes may result in fires, explo-

sions or the release of toxic gases (see Table 8).

These concerns have prompted the design of individual cells within the landfill, each of which would accept a different category of waste. The main landfill cell is divided by clay barriers into a number of subcells for specific types of hazardous wastes.[32]

Retrievable Storage

Retrievable storage refers to a secure system of long-term storing of wastes prior to recovery or destruction at a later date.

Waste storage permits certain materials to be recycled at a later date when recovery becomes more attractive financially. Another reason for storing wastes for easy retrieval is in instances where present technology is lacking to adequately detoxify or destroy select wastes. Chemicals currently in storage include PCBs and the restricted pesticide 2,4,5,-T.

Wastes are stored in drums, tanks, or ponds, depending on how hazardous or volatile the waste is.

In West Germany, the Kali & Salz Corporation (Kassel, West Germany) has been storing 40,000 tonnes of solid industrial waste per year in a salt mine since 1972.[2] Salt mines are considered suitable storage sites because of their dryness and geological stability.

Non-radioactive wastes are received from all over Europe. The solid wastes are placed in steel or plastic drums and arranged on wooden pallets. In some cases, drums are wrapped with additional polyethylene sheeting. Wastes are inventoried and systematically segregated into hundreds of different rooms within the underground salt mine.

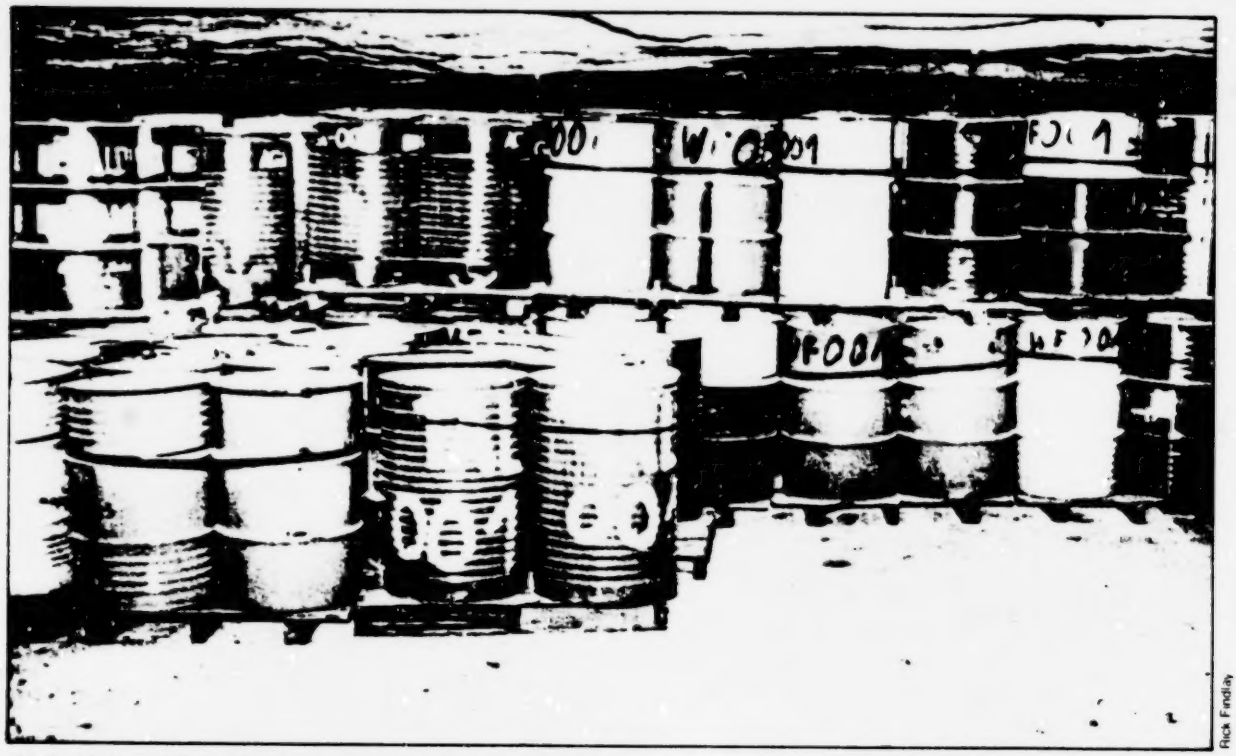
Table 7

Compatability of Synthetic Liners with Common Industrial Sludges*

	Industrial Waste						
Liner Material	Caustic Petroleum Sludge	Acidic Steel-Pickling Waste	Electro-plating Sludge	Toxic Pesticide Formulations	Oily Refinery Sludge	Toxic Pharmaceutical Waste	Rubber and Plastic
Polyvinylchloride (oil resistant)	G	F	F	G	G	G	G
Polyethylene	G	F	F	G	F	G	G
Polypropylene	G	G	G	G	G	G	G
Butyl Rubber	G	G	G	F	P	F	G
Chlorinated Polyethylene	G	F	F	F	P	F	G
Ethylene Propylene Rubber	G	G	G	F	P	F	G
Hypalon	G	G	G	F	P	F	G
Asphalt Concrete	F	F	F	F	P	F	G
Soil Cement	F	P	P	G	G	G	G
Soil Asphalt	F	P	P	F	P	F	G
Asphalt Membranes	F	F	F	F	P	F	G
Soil Bentonite (Saline Seal)	P	P	P	G	G	G	G
Compacted Clays	P	P	P	G	G	G	G

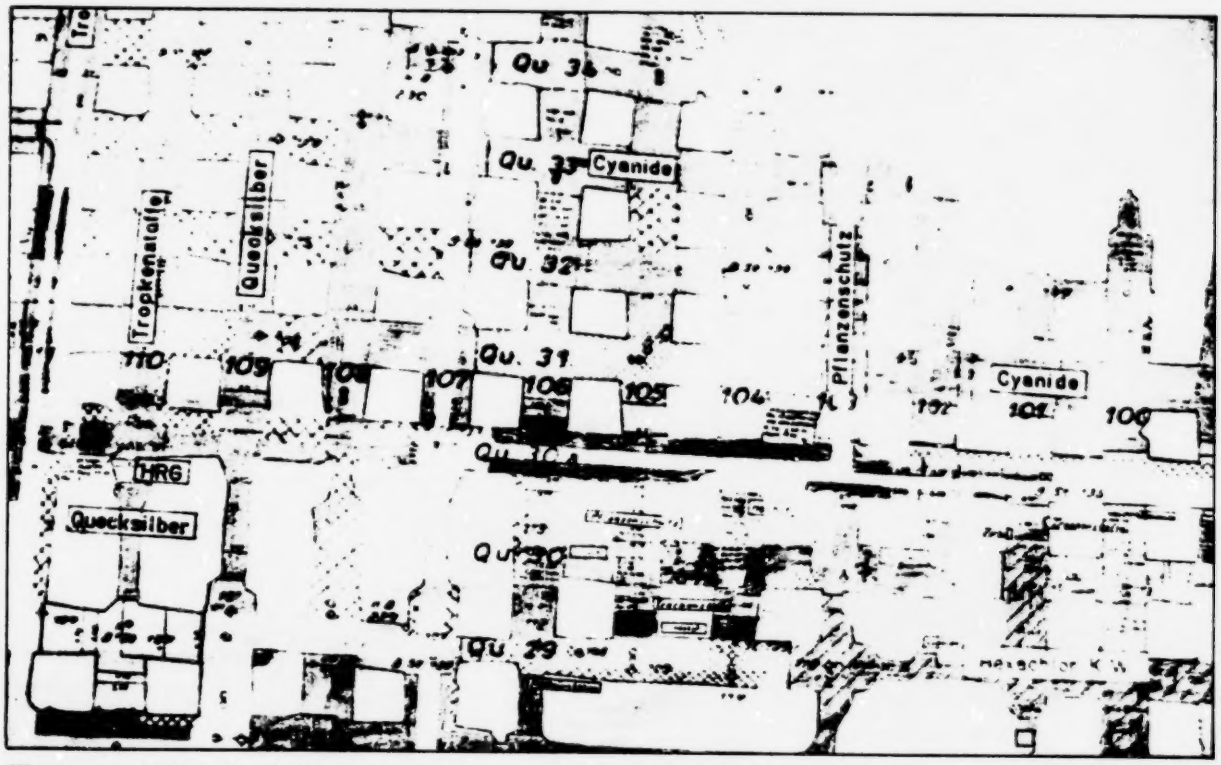
*P = poor, F = fair, G = good.

Source: *Need for Waste Management Facilities and Available Technologies: Annex One.* Prepared for the Ontario Ministry of the Environment.



Rick Findlay

At the Kali und Salz AG (Germany), wastes are stored underground in a salt mine. Incoming wastes are repackaged if necessary, and labelled for future identification.



Rick Findlay

Wastes are catalogued and placed in designated cells in the salt mine. Maps are made to keep track of the location of these stored wastes.

The German system is designed to permit easy retrieval of wastes in the future. Elaborate records are kept on the composition, reactive potential and handling hazards associated with each stored waste.

A detailed map of the mine ensures that specific wastes can be located easily. A forklift truck is used to move drum-laden pallets into storage or out for recovery.

Table 8

Potentially Incompatible Waste Materials and Components

The mixing of a Group A waste with a Group B waste may have the potential consequence as noted.

Group 1: Potential consequences: Heat generation, violent reaction.

Group 1-A	Group 1-B
Acetylene sludge	Acid sludge
Alkaline caustic liquids	Acid and water
Alkaline cleaner	Battery acid
Alkaline corrosive liquids	Chemical cleaners
Alkaline corrosive battery fluid	Electrolyte, acid
Caustic wastewater	Etching acid liquid or solvent
Lime sludge and other corrosive alkalies	Liquid cleaning compounds
Lime wastewater	Pickling liquor and other corrosive acids
Lime and water	Spent acid
Spent caustic	Spent mixed acid
	Spent sulfuric acid

Group 2: Potential consequences: Release of toxic substances in case of fire or explosion.

Group 2-A	Group 2-B
Asbestos waste and other toxic wastes	Cleaning solvents
Beryllium wastes	Data processing liquid
Unrinsed pesticide containers	Obsolete explosives
Waste pesticides	Petroleum waste
	Refinery waste
	Retrograde explosives
	Solvents
	Waste oil and other flammable and explosive wastes

Group 3: Potential consequences: Fire or explosion; generation of flammable hydrogen gas.

Group 3-A	Group 3-B
Aluminum	Any waste in Group 1-A or 1-B
Beryllium	
Calcium	
Lithium	
Magnesium	
Potassium	
Sodium	
Zinc powder and other reactive metals and metal hydrides	

Source: Need for Waste Management Facilities and Available Technologies: Annex One. Prepared for the Ontario Ministry of the Environment.

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Summary

From: Ontario Waste Management Corporation, "Facilities Development Process, Phase 1 Report", September, 1982

SUMMARY

- OWMC's liquid industrial waste and hazardous waste management system is likely to have at least three principal physical components: physical/chemical treatment facilities, an incineration process and a secure landfill.

- While there is a wide range of location possibilities - most in significant industrial waste generation areas of central and southwestern Ontario - there are several key factors contained in the information collected to date that will influence this decision:

    - To minimize the costs and risks associated with waste transport, the treatment facilities should be located as close to major waste generation areas as possible. Since approximately 70% of all liquid industrial waste and hazardous waste is generated in the highly industrialized region around the western end of Lake Ontario, treatment facilities in particular would be most cost effective if located near this area. The engineering and technical information collected to date suggests this may be feasible.

    - Approximately 58% of the estimated annual production of special waste is in liquid form. To reduce the quantity hauled to a treatment facility, particularly if it is part of a centralized system, regional transfer and dewatering stations would be desirable. Based on the geographical distribution of generated wastes, these collection areas could include Kingston/Ottawa, Windsor/Sarnia, London, Sault Ste Marie, Thunder Bay, and Sudbury/North Bay.

    - A fully centralized facility would require the largest individual site, of any option. Studies to date suggest it may be difficult to find an acreage suitable for such a facility on industrially zoned or crown-owned land within the (Zone 1) hydrogeological/geological regions. More detailed analysis is required of industrial

parks, crown land and available industrially zoned land located in Zone 2 regions, particularly in the Toronto-Hamilton area, to assess the likelihood of finding a suitable acreage for a fully centralized facility near the centre of the greatest concentration of waste generations.

- Most of the treatment technologies produce aqueous solutions containing very small amounts of residuals that must be handled by connection to a sewer system or some other means of proper monitoring and further treatment if necessary. This is one of the most important siting requirements for treatment facilities. It is not yet known whether these requirements can be met in an area with the preferred hydrogeological/geological conditions for a secure landfill.

- Evaluation of key environmental factors such as archaeology and climatology, as well as land use and transportation factors show that their importance will vary between potential sites. Specific analyses at a later stage will, therefore, be essential.

PHYSICAL/CHEMICAL TREATMENT OF SPECIAL WASTES

What are Special Wastes and Where Do They Come From?

Many different types of industrial processes generate waste which, for reasons of public health and safety, require special precautions in their collection, storage, transportation, treatment and disposal. Special wastes are those which are not suitable for treatment at water pollution control plants and should not be disposed of in municipal landfills.

A large proportion of these wastes consist of contaminated water or water-based solutions. Most of these aqueous wastes can be treated at a physical-chemical treatment facility.

What is Meant by Physical/Chemical Treatment?

Physical/chemical or "phys/chem" is a term used in industry and waste management to describe a number of waste treatment processes based on either physical or chemical scientific principles.

In general, phys/chem processes are used to:

- separate the various components in a waste stream (particular type of waste),
- chemically alter the composition of contaminants to a stable and chemically neutral form, suitable for final disposal in a landfill (the solid portion only - such as filter cake),
- prepare the water content of the wastes for discharge to a sewer or suitable body of water.

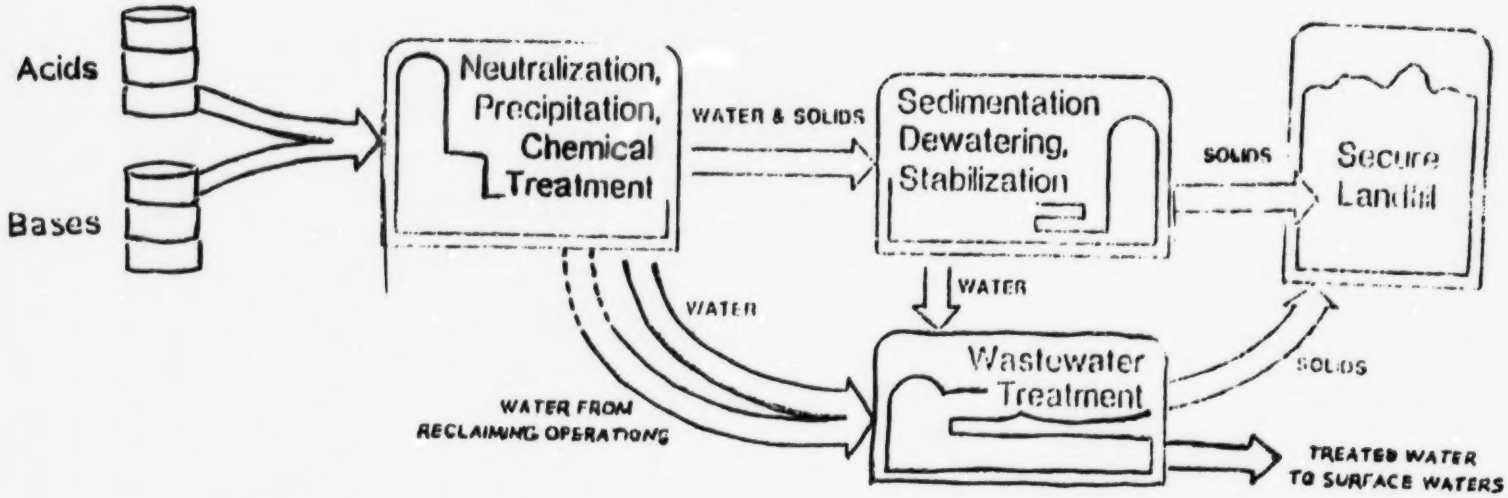
The major types of wastes treated in a phys/chem treatment plant are: oily emulsions, acidic wastes, spent pickle liquor, neutralized wastes, alkaline wastes, chromium wastes, sulphide wastes, cyanide wastes, latex wastes.

Major Components of a Phys/Chem Plant

A typical phys/chem treatment facility consists of the following:

- an unloading station and storage tank area,
- a laboratory for analyzing and verifying wastes prior to treatment and for conducting quality control testing,
- the treatment process area and equipment,
- intermediate storage facilities for wastes being processed,
- sludge de-watering facilities,
- a waste water effluent polishing system,
- process chemical storage and feed facility.
- solidification/stabilization/fixation capability.

PHYSICAL/CHEMICAL TREATMENT



From: California Study,
Toxic Waste Assessment Group,
State of California

ROTARY KILN INCINERATION

Richard V. Griffiths, P.Eng.
Project Manager, OWMC

There are two general categories of special waste -- organic and inorganic, which require different processes for their safe treatment and disposal. Most organic special waste can be destroyed by thermal destruction.

Thermal destruction of organic special waste is the burning, or incineration, of the waste at high temperatures so that the chemical bonds between the individual molecules of the waste are broken down and a reaction with oxygen occurs to form combustion product gases, such as carbon dioxide and water vapour.

Rotary kiln incineration has evolved as the most efficient and flexible system for the destruction of large volumes of toxic and hazardous waste. It can handle wastes in a variety of physical forms i.e. liquids, sludges, pastes and solids.

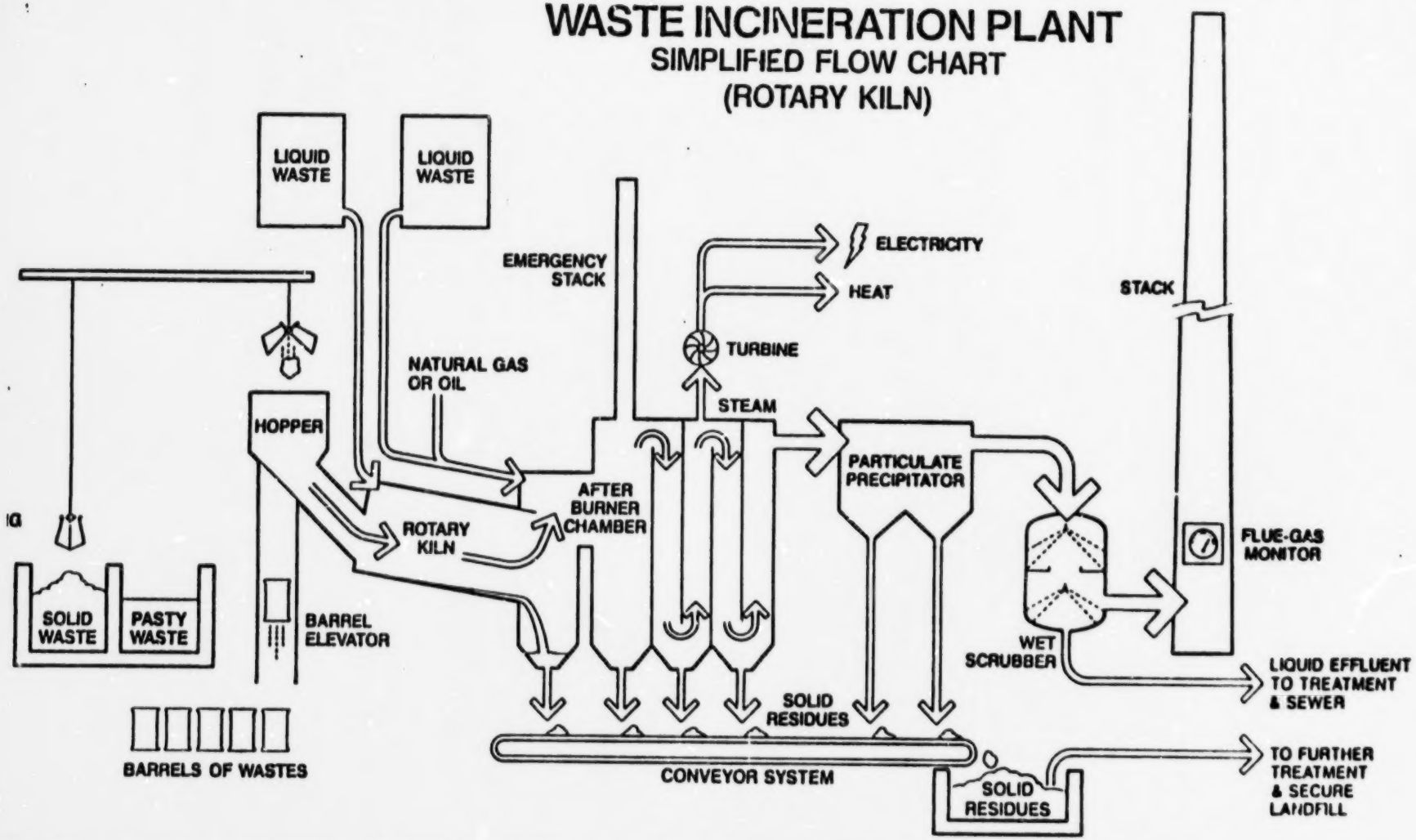
The types of wastes which can be destroyed in a rotary kiln include: organic sludges and still bottoms, solvents and organic solutions, oils and greases, oil/water mixtures, organic and oil residuals, miscellaneous chemicals and products, paint and organic residuals, inorganic sludges and residuals, and pesticide and herbicide wastes.

The Rotary Kiln has high operating efficiency and the ability to destroy virtually any type of combustable waste.

The combustion process for a well designed and operated rotary kiln incineration plant is capable of 99.999+% total destruction of the organic waste.

A typical rotary kiln special waste incinerator system is shown in the following figure.

WASTE INCINERATION PLANT
SIMPLIFIED FLOW CHART
(ROTARY KILN)



STORAGE	INCINERATION	HEAT RECOVERY	FLUE-GAS CLEANING

SECURE LANDFILL

Mr. Grant Anderson, P. Eng.
Consulting Hydrogeologist, Gartner Lee Assoc. Ltd.

The secure landfill is the ultimate resting place for the solid residues created at the various treatment facilities. Only treated wastes will be disposed at the secure landfill. This solid treated waste will have the physical characteristics of a silty soil and may harden to a concrete type of material in time.

The secure landfill is an engineered facility. The main objective of the engineering features are to:

a) prevent infiltration of precipitation and ground water so that leachate is not formed and;

b) prevent any leachate that is formed from escaping into the natural hydrogeological environment.

In as much as there is no long-term historical information regarding the integrity of engineering, for the hundreds of years that it will need to be effective, the OWMC secure landfill will be located in a hydrogeological environment that will naturally contain any contaminants that escape the engineering features. Thus, the natural hydrogeological setting becomes the second line of defence.

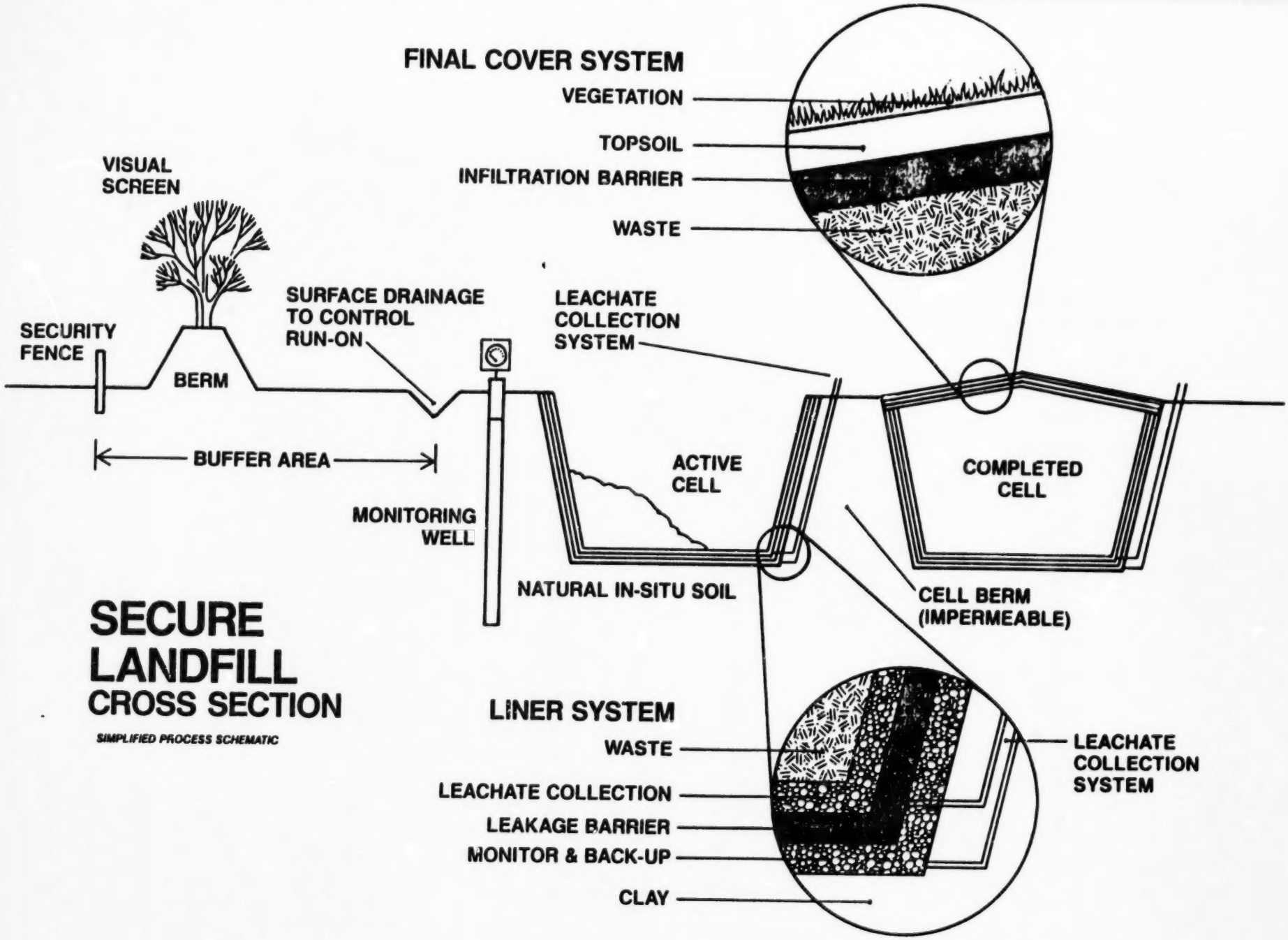
The main engineering features of a secure landfill consist of:

a) liners which can be synthetic or natural materials;

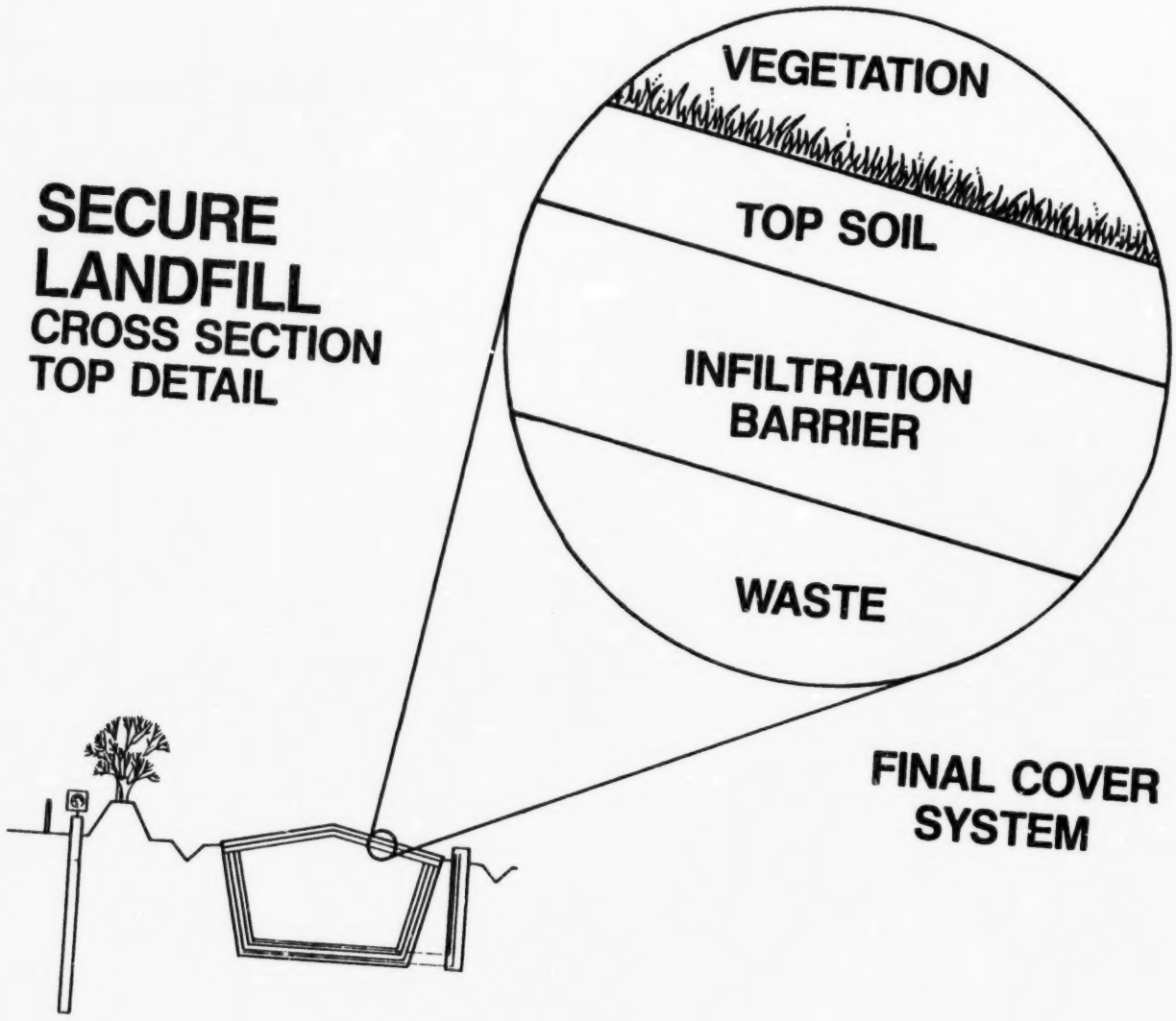
b) collector drains which can be man-made or natural materials;

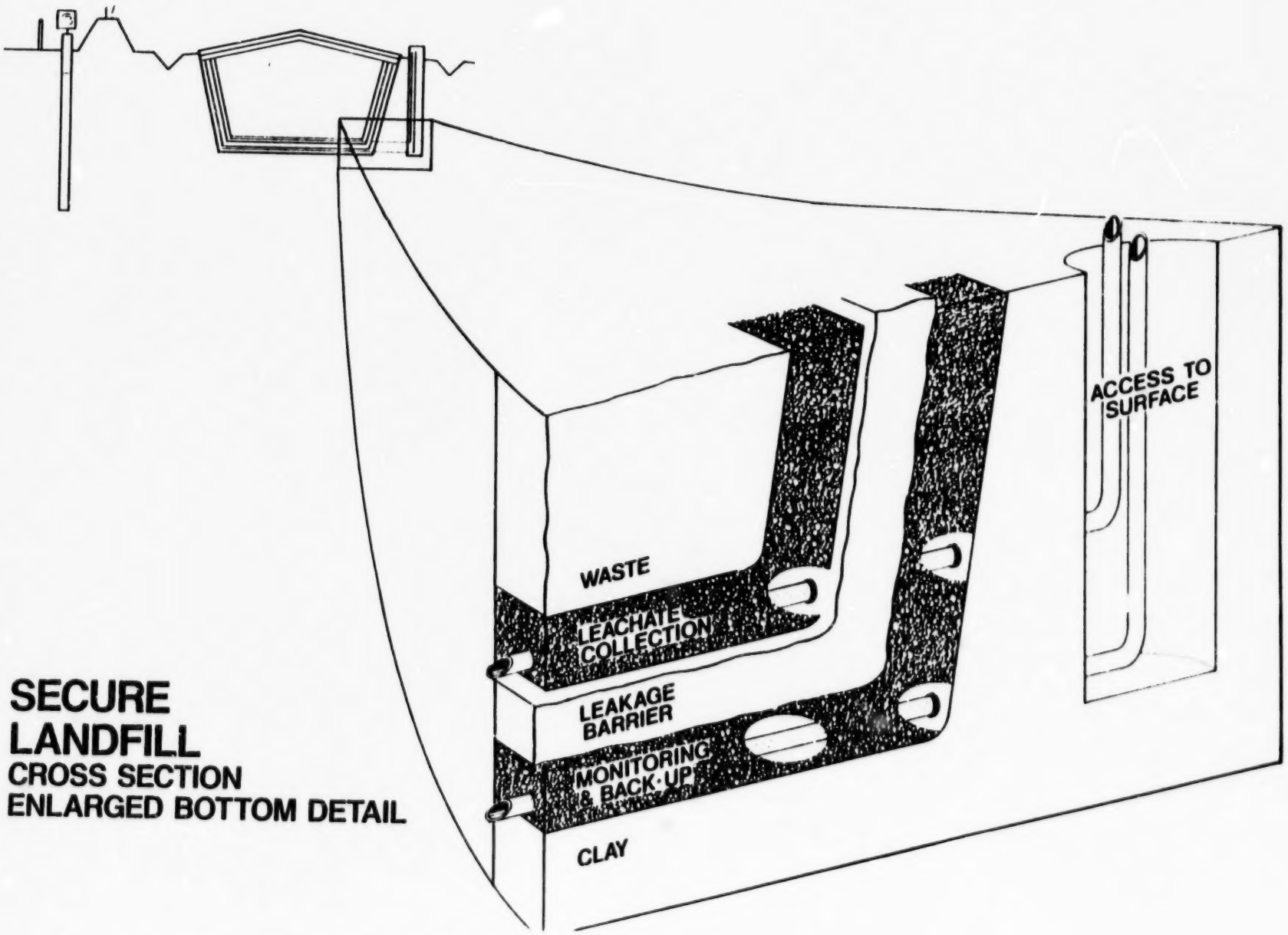
c) monitoring.

The liner and collector drain design will be mainly dependent upon the hydrogeological setting of the site and the physical/chemical characteristics of the waste. The need for a liner, the type of liner and collector drain system are all presently being evaluated. Monitoring requirements are site specific and will be assessed once the detailed site setting is known.


FINAL COVER SYSTEM
VEGETATION
TOPSOIL
INFILTRATION BARRIER
WASTE
VISUAL SCREEN
SECURITY FENCE
BERM
SURFACE DRAINAGE TO CONTROL RUN-ON
LEACHATE COLLECTION SYSTEM
BUFFER AREA
MONITORING WELL
ACTIVE CELL
COMPLETED CELL
NATURAL IN-SITU SOIL
CELL BERM (IMPERMEABLE)
SECURE LANDFILL
CROSS SECTION
SIMPLIFIED PROCESS SCHEMATIC
LINER SYSTEM
WASTE
LEACHATE COLLECTION
LEAKAGE BARRIER
MONITOR & BACK-UP
CLAY
LEACHATE COLLECTION SYSTEM

SECURE LANDFILL
CROSS SECTION TOP DETAIL





SECURE LANDFILL

CROSS SECTION
ENLARGED BOTTOM DETAIL

POOR

QUALITY

ORIGINAL